Understanding the Evolution of Transportation Pricing and Commuting at MIT: A Study of Historical Commuting Data

by

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Bachelor of Civil Engineering
University of Delaware, 2014

Submitted to the Department of Civil and Environmental Engineering
in partial fulfillment of the requirements for the degree of

Master of Science in Transportation

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2016

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ABSTRACT

In summer of 2016, the Massachusetts Institute of Technology will introduce *Access MIT*, a new commuter benefits program aimed at reducing employee single occupancy vehicle (SOV) commuting. This initiative is the latest in a long series of incremental adjustments to employee commuting benefits to provide (dis)incentives to SOV commuting and the use of transit. MIT has implemented these programs as a response to (1) state and local regulations addressing the environment, (2) tax incentives that allow MIT to offer transportation benefits to employees using pre-tax dollars and (3) dramatically increasing costs of providing parking.

This research utilizes biennial MIT commuting surveys and related data sets for years 2004 through 2014 in order to achieve a fuller understanding of historical trends in transportation benefits pricing and employee commuting behavior at the Institute. Identified trends are analyzed in order to determine which benefit program or individual commuter characteristics might best explain any observed change in mode choice over this period. The findings of these analyses provide a benchmark against which to evaluate the effects of the new commuter benefits program in a future study.

This research finds that, from 2004 to 2014, there are significant shifts in mode choice among employees commuting to and from MIT's Cambridge main campus (e.g., public transportation mode share grew from 35% to 43%). This coincided with MIT's need to convert parking dedicated land for new research and academic use. In order to explain this change, this thesis studies trends in a range of employee demographic characteristics and transportation benefits pricing characteristics for the ten-year period. This research finds that while certain employee demographic characteristics are correlated with measures of mode choice, these demographics have not changed dramatically over the decade and, therefore, pricing characteristics and exogenous factors most likely explain most of the observed shifts in employee commuting behavior to and from campus across years.

The findings of this thesis provide evidence in support of continued use of transportation pricing incentives as a means to influence employee mode choice and reduce parking demand. Finally, this research highlights a list of likely outcomes of MIT's new *Access MIT* initiative and evaluates the applicability of this thesis' findings to other urban employers, especially in high growth districts.

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ACKNOWLEDGEMENTS

John and Fred, thank you for your guidance and the time you have put in to shape this thesis. I look forward to hearing your reports of how the next step of this, Access MIT, unfolds.

Transit Lab, especially Mikel, Gabriel and Corey

Larry Brutti and Greg Harris, thanks for your help with all things data.

FHWA, thank you for making this thesis possible.

Dr. McNeil, Reid, Claire and Eily, thanks for all your help and support.

Mom, Dad, Andrew, Aubrey and Peter, thanks for everything.

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1. Introduction

This thesis presents an examination of the commuting behavior over a ten-year period of the faculty and staff of a major urban university, the Massachusetts Institute of Technology (MIT). The research aims to investigate changes in commuting behavior and to better determine the impacts of commuter pricing changes versus demographic shifts in the employee population.

The research uses MIT employee commuting surveys and related data sets for years 2004, 2006, 2008, 2010, 2012 and 2014 to perform an analysis of reported employee mode choice and employee demographic characteristics such as ownership of a private vehicle, home location and salary. By generating and comparing distributions of these descriptors across years, this thesis identifies significant trends. This analysis provides a discussion of the implications of these trends and concludes with discussion of why any obvious changes or consistencies are observed.

In addition, this research performs an analysis of the dynamics of employees' transportation benefits selection in order to better understand which factors, including pricing features and demographic features, are predictive of commuting behavior. Drawing from the findings of these analyses, the research then seeks to estimate the likely impacts of a new commuter benefits program that MIT, named *Access MIT*, will be introducing in Fall 2016 and provide a context with which to estimate the impacts of the implementation of similar programs by other large urban employers.

1.1 Background

Building and maintaining parking infrastructure has extremely significant financial cost, especially in urban areas where high land values require developers to construct multi-story aboveground or underground garages rather than relatively inexpensive surface lots. Given the cost of constructing and maintaining these parking structures, there is a clear financial incentive for businesses and other institutions to minimize the amount of parking they require. In Kendall Square, a rapidly developing business district and neighborhood in Cambridge, Massachusetts, businesses commonly experience leased parking charges on the order of $250 to $350 per space per month.

In Cambridge, a transformative period of development has largely driven the increases in the cost of providing parking to current levels. Through rezoning, the City of Cambridge has attracted enormous growth in non-residential development, especially in neighborhoods like Kendall Square, situated in southeastern Cambridge across the Charles River from downtown Boston. From 1970 to 2010, non-residential development in the City, measured in square footage, more than doubled, while the number of employees working in Cambridge increased by nearly 50% (Table 1-1). The City is committed to attracting greater development still, preparing for an additional 8.5 million square feet of new development in Kendall Square and Central Square, an adjacent neighborhood, by 2030, which will likely attract 10,000 to 20,000 added employees.

Table 1-1: Growth in Cambridge, MA (1970-2010), Source: Ferrentino

Year	1970	2010	Change
Residents	95,300	105,200	+10%
Employees	76,112	112,319	+48%
Total non-residential square feet	16 million	35 million	+120%

Kendall Square serves as an acute example of the implications the evolution of urban spaces can have on area parking costs. From the post-war period of the 1950s to the present, Kendall Square has transformed from a blighted warehouse district with ample and inexpensive parking into a nexus for commercial development, where parking has grown increasingly scarce while the employee population grows rapidly. Adjacent to MIT main campus, the area is now characterized by a significant presence of biotechnology and information technology firms and not-for-profit research laboratories. In a 2013 report outlining goals and recommendations for future growth, the City of Cambridge's Community Development Department (CDD) describes Kendall Square as "transforming into a vibrant community layering housing, recreation, retail, and dining options over the strong backdrop of commercial development driven by the knowledge economy" (2013).

During this transformative period, increasing demand for office and lab space in Kendall Square has incentivized new development on previously unused land and redevelopment of surface lots, now a cost-inefficient use of the land from a developer's perspective. The parking capacity lost in the elimination of these surface lots is often replaced by much more expensive multi-story aboveground and underground parking structures. As MIT continues to develop its campus, the construction of new academic or research space has similarly required the elimination of surface lots. To replace lost parking capacity, the Institute built in two underground parking facilities in the past 15 years as part of the Stata Center and Sloan Building, at a cost of about $100,000 per space, many times that of the cost of a surface lot space.

In addition to the impact that increasing land values have on the cost of providing employee parking in a developing urban environment, employers are especially sensitive to these costs as a result of longstanding corporate practice of offering free or heavily subsidized parking to employees. This practice is common to most major employers in the U.S., used as a means to attract and retain employee talent. Since the advent of the automobile, the federal law has allowed for all or some of the cost of employee parking to be treated as a tax-free fringe benefit, supplying a cost incentive for businesses to provide free or heavily subsidized parking to their employees. Employers adopted this practice at a time when the cost of providing parking represented relatively insignificant expense, but, as costs increase, the political difficulty of eliminating or reducing this employee benefit most often means that businesses more directly experience the growing financial burden of providing parking.

In addition to the increasing financial costs of providing parking, there are also many social costs associated with providing this benefit to employees. By making parking available and free or inexpensive for employees, businesses incentivize employees to commute by personal vehicle.

This behavior has negative implications including emissions of greenhouse gases and air pollutants and contribution toward vehicular congestion on local roadways.

To combat the negative financial implications of trends in parking costs and the negative environmental and social implications of drive alone commuting, some employers are beginning to review creative solutions to reduce employee demand for parking. These solutions, called transportation demand management (TDM) strategies, include, for example, charging employees for parking, providing a subsidy for employees' use of public transportation services and carpool matching. Each of these strategies has advantages and disadvantages. For example, introducing parking charges for employees reduces parking demand and generates revenues to recover some or all of the cost of providing parking, but is unpopular among employees, especially those who may have come to expect free parking that may have been past practice at the same company. Because of the disadvantage of this measure, companies often favor exploration of strategies that instead provide employees financial incentives to reduce parking demand. These TDM measures aim at encouraging employees to engage in methods of commuting other than by driving to work alone. Employers may pursue these strategies in order to mitigate the cost of providing parking or promote broader social benefits such as reduced vehicle emissions and improved health for employees that choose to engage in active modes for their commutes. Whatever an employer's motivation, these measures often represent a significant investment, so it is important to achieve an understanding of how they might influence employee commuter mode choice.

The question of how specific TDM strategies might affect mode choice, however, is complicated by a great number of factors outside of an employer's direct control, such as demographic characteristics like employee home location and automobile ownership, and exogenous factors such as general economic conditions and gasoline prices. These factors most likely represent significant predictors of employees' commuting behaviors, with or without the implementation of TDM measures. This research seeks to measure the effects of these factors on mode choice and investigate the role of these factors in an evaluation of the effectiveness of TDM strategies implemented by MIT over the past decade.

1.2 MIT Context

Every two years, the MIT Office of the Provost administers a commuting survey of the MIT community in late October and early November. This survey was initially a response to a City of Cambridge regulation intended to incentivize major employers to encourage reduced use of automobiles in commuting. The survey responses represent a wealth of data on employees' and students' behaviors and perceptions relating to transportation at the Institute, including reported information on employee commuter mode choice. These surveys also include questions regarding employee demographics, including inquiries on home location and automobile ownership. This thesis uses these MIT commuting surveys and related data sets for years 2004 through 2014 to investigate the relative effects of demographic characteristics, exogenous factors and TDM measures implemented by the Institute on employee mode choice.

MIT main campus is located in southern Cambridge across the Charles River from Boston's Back Bay, a major neighborhood just west of Boston's central business district. The campus is adjacent to three Cambridge neighborhoods: Kendall Square to the east, Central Square to the north and Cambridgeport to the north and west. Members of the MIT community have reasonably good access to MBTA rapid transit services with Red Line stations located at Kendall Square and Central Square. Kendall Square Station is located approximately 0.3 miles east of Building 8, an approximate center point of central campus, which is home to most of the academic, office and laboratory space on campus. Central Square station is located about three quarters of a mile away from Building 8. The campus is also well served by a number of MBTA and privately operated bus routes. With bus stops at 77 Massachusetts Avenue, the MBTA Route 1 and CT1 buses offer very accessible service to and from Back Bay, Dudley Square, the Boston Medical Center, Central Square and Harvard. The CT2 bus offers service to and from destinations such as Sullivan Square and the Longwood Medical area, stopping along Vassar Street, which runs east-west along the northern edge of the main campus. A number of additional MBTA bus routes operate through Kendall Square and Central Square. Members of the MIT community also have access to shuttle services around campus and to and from common student residential destinations such as Boston, Brookline and Somerville. Additionally, the Institute participates in the Charles River Transportation Management Authority's (CRTMA) EZ-Ride shuttle, which provides service to and from North Station, Lechmere Station, Kendall Square Station and Cambridgeport. For those driving to campus, the Institute offers commuter parking in a number of surface lots, aboveground garages and underground parking facilities around campus. In total, MIT provides a total of approximately 4,100 parking spaces in 53 areas or facilities.

At present, MIT is home to a student population of approximately 11,000 and employs approximately 12,000, including faculty and research staff, some of which work at off-campus laboratories. To accommodate its commuting population, the Institute currently offers employees and students subsidized parking permits and transit passes. Employees can purchase parking permits and transit passes through the Parking and Transportation Office using pre-tax dollars per federal law on qualified transportation fringe benefits. For parking, two major options are offered – a regular commuter permit, providing unlimited access to campus parking for an annual fee, and an occasional/evening permit, offering access to parking for a smaller annual fee and a daily fee paid for each day that the employee uses Institute parking. MIT incurs a cost of approximately $3,500 per space per year to provide parking, meaning a regular parking permit is subsidized at about 55%. MIT's newest underground parking spaces, however, are subsidized to a much greater degree, given their higher costs, estimated at approximately $6,000 annually (Gates, 2015). MIT currently subsidizes MBTA monthly passes at a level of 50%. Employees can purchase these passes through MIT to benefit from this subsidy, paying $37.50 rather than $75 for a LinkPass, which provides unlimited access for a month to the MBTA's bus and rapid transit services. Commuter Rail passes are priced by zone, ranging from $182 for a Zone 1 monthly pass to $362 for a Zone 10 monthly pass. Through MIT, employees can purchase these commuter rail passes for half the MBTA market price (Table 1-2).

Table 1-2: Summary of current transportation offerings at MIT

Parking		
Permit Name	**Annual Fee**	**Daily Fee**
Regular Commuter	$1,600	--
Occasional/Evening	$89	$8.50
Transit		
Transit Benefit	**Monthly Cost (Subsidy)**	
LinkPass	$37.50 (50%)	
Commuter Rail Pass	$91 - $181 (50%)	

With the approach of the coming 2016-2017 academic year, the Institute is preparing to implement a redesigned transportation benefits program, branded as "*Access MIT*." The recommended design of *Access MIT* reflects years of collective research effort by a number of graduate students and research staff affiliated with the MIT Department of Civil Engineering's Public Transportation Research Group. These recommendations call for (1) the introduction of a universal pay-per-use transit pass embedded in employees' MIT identification cards for simplicity and security, (2) daily parking pricing for parkers and (3) a commuter dashboard, an online interface with which users can track their commuting behaviors and investigate a wide range of commuting alternatives personalized for each individual employee. The major change in program benefits of *Access MIT* involves a shift from annual to daily parking charges. In academic year 2016-2017, regular and occasional parkers assigned to gated parking facilities will pay a $100 permit fee plus a $10 daily fee for each day that they park. The total of these employee charges will be capped at $1,760 for the year. Ungated parking facilities (about 600 spaces) do not allow the Institute to monitor daily usage, so parkers assigned to these lots will continue to pay a flat annual fee of $1,760. In addition, all benefits-eligible employees are provided with a transit pass to be embedded into their ID cards, giving the employee access to MBTA bus and rapid transit services. Any use of these transit passes is 100% subsidized, meaning employees will have zero-cost access to local public transportation services. For employees wishing to purchase commuter rail passes, MIT will provide an increased subsidy, 50% of the value plus an additional $37.50 discount. And any transit riders requiring parking at MBTA parking facilities will be reimbursed 50% the cost of parking up to a value of $100 per month.

1.3 Motivation

MIT faces two major constraints in providing parking to its commuting population. First, the Institute is subject to a parking cap, dictating that the Institute can provide, at maximum, approximately 3,700 parking spaces devoted to commuter use (Block-Schachter, 2009). MIT has been subject to this requirement since 1973, when state authorities and the City of Cambridge began enforcing a cap on non-residential parking in response to the greater Boston region's classification as a non-attainment area for air quality standards established in the Clean Air Act, passed in 1970. Second, the cost of providing parking represents a significant expense to the Institute. As MIT and the area around it have become increasingly developed and attract increasingly larger numbers of employees, the costs of providing, maintaining and replacing parking have grown significantly. While historically reluctant to charge employees for parking, in 2001, the Institute announced a $400 annual fee for employee parking and a commitment to increasing this fee by 11% annually. This and other trends, including the implementation of more progressive public transportation benefits for employees in recent years, suggest an increased sensitivity to the cost of providing parking at the Institute.

The structural and financial constraints that MIT faces in providing parking have parallels to the experiences of other urban universities and more generally, other large urban employers such as major hospitals. While the City's enforcement of a parking cap represents a structural constraint that may not be common to many urban universities and institutions, the effect of this constraint can be likened to the scarce land development potential that urban employers, including MIT, face. Due to these constraints, it is in MIT's and other urban employers' best interests to effectively manage employee commuter demand for parking.

In addition to these constraints, other factors may represent a significant force driving employers' decisions to explore and implement TDM strategies. These factors may include concerns relating to environmental health, the health of employees or the effects of roadway congestion. MIT, for example, announced its "Walk the Talk" initiative in 2006, stating a commitment to decrease the Institute's contributions to greenhouse gas emissions. The Institute's Office of Sustainability is promoting MIT's Fall 2016 introduction of the *Access MIT* commuter benefits program as a major initiative. The program represents an opportunity for the Institute to not only reduce employee demand for limited spaces in often aging parking facilities in need of replacement, but also a means by which to promote increased community consciousness of the environmental costs of commuting, especially by means of a personal vehicle.

Over the past decade and despite a growing employee population, the Institute has enjoyed relative success in managing demand for commuter parking, observing an estimated 5% reduction in the proportion of employees describing themselves as SOV (Single Occupancy Vehicle) commuters from 2004 to 2014 (MIT Institutional Research, 2016). Some administrators seeking to avoid the expense of added incentives have stated that changing employee demographics, and not increasing parking charges and improved affordability of public transportation alternatives, have been the primary drivers of this observed behavioral change. This thesis seeks to test this hypothesis and, more broadly, investigate how employee characteristics and external factors influence employee mode choice and what role these factors play in evaluating the effectiveness of TDM strategies implemented by the Institute in the last decade.

The goal of this thesis is to apply the lessons learned in this research effort to predict the effectiveness of TDM strategies given observed measures for external factors that have been shown to influence employee commuter mode choice. This research is particularly relevant as the Institute prepares to implement *Access MIT* in academic year 2016-2017. *Access MIT* represents a significant learning opportunity regarding a range of TDM measures and their impact on employee commuting behaviors at the Institute. This thesis seeks to strengthen this opportunity by providing an analytical infrastructure with which estimate and evaluate the effects of *Access MIT* on employee commuter mode share. While this research evaluates data reflecting MIT's policies, challenges and employee population, this work hopes to extrapolate lessons learned to other urban employers exploring TDM strategies as a way to reduce employee demand for parking.

1.4 Objectives

The following are the specific objectives of this research:

Present a review of the relevant TDM and other literature related to commuting to larger urban employers and provide an overview of the history of TDM at MIT.

Conduct an analysis of trends in descriptors of employee commuting behavior and employee demographics. Visualizations and descriptive statistics are generated for variables describing mode choice and employee characteristics expected to be predictive of mode choice in order to determine significant trends in these descriptors over the studied time period.

Perform an analysis of the dynamics of employees' transportation benefits selection and parking frequency across years in order to determine which factors are driving changes in employee mode choice. This analysis seeks to examine the influence of various factors on observed changes in transportation benefits selection and behavior. These factors include transportation benefits pricing characteristics, employee demographics, measures of economic trends and gas prices.

Predict the outcomes of MIT's new commuter benefits program, *Access MIT*. Building on the findings determined in the analyses described above, this thesis discusses the likely impact of the set of TDM measures represented in the recommendation for the Institute's *Access MIT* program, to be implemented in the summer of 2016.

1.5 Organization

The organization of this thesis is modeled by the ordering of objectives presented in section 1.4. Chapter 2, a literature review, defines TDM and provides a historical overview of the implementation of TDM measures at MIT. This chapter introduces the national, state and local level legislation and proceedings relevant to the development of TDM as an established part of political consciousness in the City of Cambridge. Chapter 3 presents the methodology and findings of an analysis of trends in mode choice and employee characteristics. Here, the variables to be investigated are defined, analyzed and examined for evidence of trends over the studied time period. Chapter 4 presents the methodology and findings from the analysis of the dynamics of employees' transportation benefits selection and parking frequency performed in this research. This chapter presents the findings from the analysis and discusses which factors are driving changes in employee mode choice. Finally, Chapter 5 concludes by discussing important trends relating to TDM at MIT and provides an estimate of the likely impact of MIT's new commuter benefits program, *Access MIT*, on employee mode choice. In addition, this chapter discusses the applicability of this thesis' findings to other large urban employers and identifies opportunities and recommendations for future research.

2 Review of Transportation Demand Management and MIT Background

2.1 Introduction

The term transportation demand management (TDM) is used to describe any low capital-intensive measures a jurisdiction or employer puts in place to influence the travel behaviors of resident and employee commuters. This chapter outlines a number of TDM strategies implemented by urban employers, with a special focus on those most relevant to the Institute's design of its new transportation benefits program, *Access MIT*. Next, this chapter provides a brief overview of legislation enacted on the national, state and local level that is most relevant to MIT and other Cambridge employers. Finally, the chapter concludes with a summary of the most recent history and current state of TDM at MIT, providing a context for the analyses to be presented in the next chapters.

2.2 Urban Employer TDM

Urban employers explore and implement TDM strategies to reduce the number of employee SOV trips to and from the workplace. These employers pursue these strategies for a number of reasons. By reducing demand for SOV commuting, employers can generally reduce parking costs. Employers can also use TDM measures to pursue longer-term goals, such as to replace parking infrastructure with more valuable uses for the land, like additional office or laboratory space or employee amenities. In addition, many employers implement TDM measures to be better corporate citizens. Using incentives to eliminate employee SOV trips reduces an employer's contributions to greenhouse gas emissions and local roadway congestion.

Urban employers, especially, are increasingly exploring TDM measures because of the high parking costs associated with urban areas and because urban public transportation systems generally represent a viable commute alternative for many of their employees that may drive. This section discusses some of the most popular TDM strategies used by urban employers. Daily parking pricing and subsidized transit passes are highlighted because of their relevance to the *Access MIT* program, which will be fully introduced for the 2016-2017 academic year.

2.2.1 Parking Pricing

Whether or not an employer charges employees for parking is the most important factor in mode choice. In their paper, "Commuter mode choice and free car parking, public transportation benefits, showers/lockers, and bike parking at work: evidence from the Washington, DC region," Hamre and Buehler show that charging employees for parking is the best determinant of employee mode choice (2014). They find that employees respond to parking charges, and this effect is significant regardless of whether or not other TDM measures are also used, such as transit benefits or amenities for cyclists, for example. Employees with the opportunity to take advantage of benefits such as transit subsidies and bicycle amenities who had to pay for parking were more likely to use transit or active modes for their commute. For employees with comparable transit benefits and active mode incentives and free parking, however, Hamre and Buehler show that the availability of free parking largely cancels out the effect of transit and active mode incentives. This shows that charging employees for parking is an effective incentive for employees to change their commuting behaviors, with or without the use of additional incentives. Other studies have arrived at similar conclusions. For example, a 2006 discrete choice survey of commuters in Vancouver finds that parking charges and road charges make the largest impact on respondents' mode choice (Washbrook, Haider and Jaccard, 2006). Another study, in Portland, Oregon, found that the introduction of parking charges for previously free parking was the most important factor in driving observed changes in mode share following the implementation of a regional TDM plan involving the new parking charges and the promotion of subsidized transit pass programs (Bianco, 2000).

For employers that do charge employees for parking, the way in which they do so also has a significant role on employee mode choice. Many of these employers charge employees for parking on a monthly or annual basis. With monthly and annual parking charges, the employee incurs a one-time cost, after which, the marginal cost of parking an additional day is zero for that time period. This forces employees to make their decisions about driving and parking in the context of relatively long time periods and provides employees purchasing parking with little incentive to change from SOV commuting on an occasional basis. By charging for parking on a daily basis, employees incur a cost for only the days that they park. Daily parking charges greatly reduce the "sunk" cost of parking, while increasing the marginal cost of parking significantly above zero. Daily parking pricing also provides the advantage of providing employees who may only need to drive rarely greater flexibility and provides employees that regularly drive a greater incentive to use other modes occasionally.

There is also evidence that daily parking pricing structures are more effective in reducing employee parking demand when compared to charging for parking on a monthly basis. In a University of California, Berkeley study of parking demand on campus, Ng determines price elasticity of parking demand to be -0.97 for fixed monthly parking charges and -1.22 for daily parking charges (Ng, 2014). This suggests that individuals reduce their demand for parking more significantly as a result of an increase in the parking charges incurred on a daily basis than as a result of an equivalent increase in a monthly parking charge. This is likely due to the increased saliency of daily parking charges, which may be incurred through specific transactions every day, compared to monthly charges, which an individual is likely not thinking about on a day-to-day basis.

2.2.2 Subsidized Transit Passes

While charging employees for parking represents an effective disincentive for employee SOV commuting, subsidizing transit is another TDM strategy that employers may use to incentivize employees to reduce their parking demand. Employers in urban areas, well served by transit, are most likely to offer transit subsidies to their employees. Transit subsidies can be offered independently or along with other incentives or disincentives, such as parking charges. As was shown by Hamre and Buehler, however, transit subsidies tend to be most effective in affecting change in employee mode share in employee mode choice in conjunction with parking charges.

Employers can subsidize some or all of the cost of individual transit trips or passes, reducing the cost of taking transit for their employees. How employers choose to subsidize transit is largely dependent on the fare media and pass types offered by the local transit authority. In Boston, for example, the MBTA offers a number of monthly passes valid for unlimited rides on a defined subset of MBTA services. At present, MIT subsidizes all MBTA monthly passes at a level of 50%. By effectively lowering the cost of transit for employees, employers encourage more employees to choose to buy passes and commute by transit rather than SOV, perhaps even on a part-time basis.

Some employers go further than simply lowering the cost of transit passes. Many urban employers and universities around the country have introduced universal access transit pass programs (universal pass programs, for short), which provide transit passes to all employees and/or students. Employers may provide these universal passes at zero cost to the employees or require employee contributions. Universal pass programs provide the advantage of encouraging transit use by reducing the effective marginal cost of transit to zero for the affected employee population. Either a pass is provided to every employee entirely for free, or all employees pay a small sum into the system to get their passes, after which any use on the card has zero marginal cost the employee. A possible challenge of universal pass programs, however, is that in order to be successfully introduced, they must have the support of the employees that will pay into the system. For this reason, universal pass programs are generally much more politically feasible when the employer subsidizes all, or nearly all, of the cost of the passes.

In order to encourage the creation of universal pass programs, transit agencies may even contribute subsidies of their own in the form of discounts. Transit agencies are generally open to working with employers to establish universal pass programs because universal pass programs present an opportunity to significantly increase ridership. In Portland, Oregon, for example, TriMet, the local transit authority, has partnered with hundreds of employers to introduce universal pass programs at those companies. Participating employers pay the agency for all the rides taken using employees' universal passes on a pay-per-use basis. These programs have helped many Portland employers move closer to achieving their TDM goals as well as dramatically increased ridership and revenue for TriMet.

While universal access pass programs likely do little to change the behaviors of full-time transit riders (they will continue to ride transit), universal passes have been shown to dramatically increase transit ridership among employees that did not previously ride transit often. In the late 1990s, the Lloyd District, a commercial district in Portland across the Willamette River from downtown, introduced a regional TDM plan that involved putting into place parking meters to begin charging for previously free street parking, limiting new parking supply and marketing TriMet's universal pass program to area employers. A 1999 case study of this plan found that by a year after the implementation of the regional TDM plan, SOV mode share among employees with access to a universal pass had decreased by 19%, compared to a 2% increase in SOV mode share for employees whose employers' did not have a universal pass program (Bianco, 1999). In addition, over the study period, employees with access to a universal pass program who were infrequent users of transit before the plan's implementation significantly increased the frequency with which they rode transit. For example, employees with access to the universal pass who reported riding transit one to eight times per month were found to have increased their use of transit by 13% and those who reported riding transit nine to 19 times per month increased transit usage by 22% (Bianco, 1999).

The example of the Lloyd District suggests that expanding employee access to transit passes helps employers to capitalize on the use of parking charges as a way to reduce employee parking demand. Especially in conjunction with the use of daily parking pricing, universal transit helps eliminate the "binary" problem that is often created by less flexible parking and transit pricing schemes. When offered the choice of a monthly parking pass or a monthly transit pass, employees are forced to make a decision of whether it would be best for them to drive all the time or take transit all the time. Bundling daily parking pricing and universal transit represents a pair of effective incentives that also empowers employees with greater flexibility. Many employees' personal circumstances dictate that they must drive to work some days (e.g. to run errands, to pick up a child from school or daycare, etc.). Even if these obligations require an employee to drive only a couple days per week, these employees will likely become full-time parkers if given a choice of monthly parking or monthly transit. If the employer were to instead offer universal transit and charge for parking on a daily basis, however, this same employee will likely respond to these incentives by driving only on the days when it is necessary. Finally, combining a universal pass with a shift to daily parking charges, and higher parking charges, may ease the political concerns of potential adverse impact on employee morale.

2.2.3 Other TDM Measures

In addition to parking pricing and subsidized transit passes, there are many other TDM measures that urban employers may implement in order to reduce employee parking demand. As an alternative to implementing parking charges, employers may implement parking cash-out programs. In a parking cash-out program, employees are given the option to take a parking space or instead receive payment for forgoing the parking space. In contrast to offering free parking, parking cash-out helps employees better recognize the value of a parking space, because in order to park, they must forgo a cash reward or similar incentive. Parking cash-out may be an attractive option for employers where introducing parking charges may be especially politically difficult.

In addition to subsidized transit passes, employers can also offer additional incentives to encourage employees to use public transportation. These include providing first-mile, last-mile shuttle services between a transit station and the workplace. Emergency ride home programs also serve as an incentive for transit riders. These programs provide a free taxi ride home from work to employees not driving to work in the case of an emergency. This allows employees to use modes other than SOV without completely sacrificing access to a car should the need arise.

To incentivize use of active modes, employers may offer cash subsidies for employees that do not use parking or transit. Some companies may simply issue payment to employees, while others may offer a subsidy in the form of reimbursement. For example, a company may offer bicycle commuters up to $20 per month in bicycle repair and maintenance expenses. Employers can also encourage use of active modes by providing amenities such as bicycle parking, showers and locker rooms.

2.3 National, State and City TDM

Much of TDM at MIT has been guided by federal, state and local legislation and initiatives. In 1970, the federal government passed the Clean Air Act (CAA), designed to control air pollution.

The CAA provided a framework for state coordination with the EPA to use regulatory measures to address regional non-compliance with ambient air quality standards established by the law (EPA, 2016). To address non-compliance with these air quality goals in the greater Boston area, in 1973, the EPA put in place a cap on non-residential parking in Cambridge, which the City enforced intermittently until 1997 (Ferrentino, 2013). This cap affected MIT and a great number of other Cambridge employers. MIT, for example, was committed to providing no more parking spaces than required to accommodate 36% of its commuting population at the time (Block-Schachter, 2009). This committed MIT to providing no more than about 3,700 spaces designated for commuter use.

Over the approximately 25 years during which this parking "freeze" was intermittently enforced, there was a great deal of controversy and political tension among City representatives, businesses and community groups[1]. This debate led to Cambridge adopting new legislation to replace the freeze in 1998. The redesigned regulation, the Parking and Transportation Demand Management Ordinance (PTDM), represented a shift to a more multifaceted policy, targeting commuter choice rather than the physical parking stock. Many of the employers subject to the parking cap were grandfathered into the PTDM regulation. MIT, however, was not made subject to the PTDM ordinance on the condition that the Institute continues to observe the cap on parking and to make biennial reports to the State and to the City on the MIT community's commuting mode split.

2.4 TDM at MIT

As a result of the 1973 cap on non-residential parking put in place by the EPA and the City of Cambridge, MIT was committed to providing no more than 3,700 spaces devoted to commuter use. While this measure represents the earliest significant implementation of TDM measures to control automobile commuting to MIT, conversation concerning how to manage parking demand extends to as early as a couple decades earlier. Today, the Institute continues to observe the parking cap requirement. While this exempts MIT from participation in PTDM ordinance (which generally emphasizes the implementation of employer-based TDM strategies), it has taken an increasingly progressive approach to TDM in recent years, employing many of the measures promoted by the City in the ordinance. While there have been many recent advances by MIT in the area of TDM, much of the Institute's history since the advent of automobile commuting is characterized by resistance to and rejection of many of the measures now implemented. This section provides an outline of the history of the exploration and implementation of TDM measures at the Institute, focusing especially on parking pricing and subsidies for employees' use of public transportation.

2.4.1 Parking Pricing at MIT

In the 1950s, the city of Cambridge installed parking meters on Memorial Drive, a major roadway running along the southern edge of MIT main campus. This development, combined with general trends of increasing use of automobiles, established parking demand management

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[1] Cara Ferrentino's Master in City Planning thesis, "Cambridge in Transition: Regulating Parking in a Growing City," provides a comprehensive discussion of the intermittent enforcement of the parking freeze and the influence that conflicts among stakeholders had on shaping the eventual Parking and Transportation Demand Management (PTDM) legislation.

as a significant issue for the Institute for the first time. In 1957, a special committee recommended the introduction of an annual parking charge of $20 ($170 in 2016 dollars), stating the following:

> Underlying the entire parking problem at the Institute is the fact that parking facilities are a direct expense to the Institute, and that in the future these costs, both original and operating, are going to rise at a rapid rate. We strongly recommend that a policy of nominal charges for parking be adopted to help eliminate non-essential demand, and to help defray operating costs and/or build up capital toward the construction of new parking structures.

The special committee's suggestion of implementing this annual parking charge was accompanied by a call for the construction of additional parking capacity on-campus. Despite its recommendation for investment in new parking facilities, the committee's report represented a first formal acknowledgement of the future insolvency associated with providing on-campus parking at the Institute without the introduction of parking charges. MIT took no action on the recommendation of a $20 annual parking charge.

Calls for the implementation of a parking charge resurfaced in 1960, at which time the Institute was building a new on-campus parking lot. To help offset the capital costs of this new construction, estimated at approximately $2,500 per parking space, a new recommendation suggested implementing a parking charge of $30 per semester ($240 in 2016 dollars). Again, MIT elected to not charge anything for parking, taking no action on the proposal for a $30/semester parking fee.

In 1975, MIT approved the first charge for on-campus parking, a $5 administrative fee ($20 in 2016 dollars). By 1990, this administrative fee was raised to $10 ($20 in 2016 dollars), and, in the late 1990s, the Institute implemented its first annual non-administrative parking charge. In 2001, at which time the annual parking charge was $400, MIT announced it would begin raising parking charges by 11% per year. From 2001 to present, the price of parking has been increased by approximately 11% each year, with the exception of 2004, due to a temporary freeze in employees' salaries. Table 2-1 below shows the historical rates for a regular annual parking permit at MIT for academic years 2001-2002 through 2015-2016.

As the price of a basic annual parking permit (termed the "regular commuter" permit) has increased, MIT Parking Services has also established a number of alternative permit types to better manage demand for campus parking and accommodate the diverse commuting preferences of the employee population. Each of these permits types is characterized by different pricing structures and privileges. The most notable of these alternative offerings is the occasional permit. For academic year 2015-2016, employees opting for the occasional permit paid an annual sticker fee of $89 plus a daily charge of $8.50 for each day they park. Table 2-2, below, outlines the basic pricing characteristics of the regular, economy regular, occasional, economy occasional and carpool permits offered by the Institute Parking and Transportation Office for the current academic year.

Table 2-1: Annual cost to the employee for a regular commuter annual parking permit for academic years 2001-2002 through 2015-2016

Academic Year	Annual Fee
2001-2002	$400
2002-2003	$444
2003-2004	$466
2004-2005	$518
2005-2006	$575
2006-2007	$638
2007-2008	$708
2008-2009	$786
2009-2010	$872
2010-2011	$968
2011-2012	$1,074
2012-2013	$1,192
2013-2014	$1,323
2014-2015	$1,455
2015-2016	$1,600

Table 2-2: Basic pricing characteristics of parking permits offered by the MIT Parking and Transportation Office (academic year 2015-2016)

Permit Name	Annual Fee	Daily Fee
Regular Commuter	$1,600	--
Economy Regular Commuter	$859	--
Occasional/Evening Parking	$89	$8.50
Economy Occasional Parking	$89	$3.00
Carpool/Vanpool	$800	--

The various pass types provided by MIT are offered with the goal of providing employees that need to drive with increased flexibility. Employees seeking to reduce parking costs can opt for the carpool/vanpool permit, or the economy regular or economy occasional permits, agreeing to park only at facilities located on MIT's west campus. The occasional and economy occasional permits allow employees to remain eligible for a subsidized transit pass, representing attractive options for those employees that regularly take public transportation or engage in another method of commuting other than driving alone.

2.4.2 Promoting Use of Public Transportation at MIT

In 1996, MIT began offering a subsidy of $10 per month for employees and students purchasing transit passes. Over the next decade, the Institute increased this subsidy to 50% of the cost of a monthly pass for bus and rapid transit. In 2004, the first year of the ten-year study period examined in this thesis, MIT subsidized monthly Combo passes (the closest equivalent to the LinkPass, which was introduced in 2006) by 50%, and local bus passes by about 60%.

Commuter rail and commuter boat passes were subsidized by a flat contribution of $59, or 50%, whichever was less. In summer of 2008, the Institute announced it would be increasing the transit subsidy to 50% for all pass types, including passes for all commuter rail zones and the commuter boat. This announcement was part of a broader commuter benefits initiative promoted at the beginning of the 2008-2009 academic year. Part of this initiative included an offer of a free transit pass for the month of September for full time drivers. About 700 full time drivers signed up for the offer of free transit.

Since 2008, the Institute has continued to subsidize all MBTA pass types by 50%. In 2010, MIT introduced another initiative, the Mobility Pass pilot program. For this program, the Institute distributed new MIT ID cards with an embedded transit chip to full time parkers. Any use of the transit pass embedded in the new ID cards was paid for entirely by MIT. The goal of the program was to encourage full time drivers to occasionally try taking transit to commute to and from campus instead. As another component of the program, MIT began embedding stored value transit chips in students' ID cards to promote increased use of transit by students. The stored value chip in the ID card functions exactly the same as the MBTA's smart card, the Charlie Card. Students can load money onto the card and use it to pay fares throughout the MBTA system. MIT makes no financial contribution towards students' transit expenses in this way, but it has eliminated the start-up cost to students new to the Boston area of having to collect their own Charlie Card, from one of a limited number of sales locations at MBTA stations. And for those students who commit to relatively frequent use of the MBTA, MIT subsidizes 50% of the cost of a monthly or semester pass.

MIT also promotes the use of public transportation with other resources and services. The Institute participates in the Charles River Transportation Management Authority's (CRTMA) EZ-Ride shuttle service. The EZ-Ride is a bus route serving Cambridgeport, MIT's northwest campus, Kendall Square, Lechmere and North Station. This service encourages transit use among MIT employees by providing first-mile, last-mile service for employees' commutes to and from MIT by means of the MBTA's North Station commuter rail lines. MIT also provides a number of shuttle services that provide access to destinations elsewhere in Cambridge, in Boston, and to MIT's Lincoln Labs and Wellesley College. Additionally, MIT offers an emergency ride home program. This program provides a means for employees commuting to campus by means other than SOV to have the cost of a taxi ride home fully reimbursed should an emergency occur.

2.5 Summary

This chapter provided a brief overview of TDM measures – most notably, parking pricing and transit subsidies. Urban employers generally use TDM measures to reduce employee parking demand and promote sustainable transportation. Achieving decreased levels of employee parking demand allows employers to reduce parking costs and be better corporate citizens – decreasing parking demand also has positive implications for the environment and levels of traffic on local roadways. In the long term, effectively reducing parking demand may even allow employers reallocate land used by parking infrastructure to more productive uses for that land, such as additional workspace.

In the 1970s, MIT became subject to a cap on parking put in place by the EPA and City of Cambridge. The Institute is still subject to this cap and has engaged in increasing progressive TDM measures to manage parking demand on campus in recent years. MIT's new commuter benefits program, *Access MIT*, to be completely introduced in the 2016-2017 academic year, represents a new, more aggressive application of a range of TDM measures. The program involves increasing parking charges and adopting daily parking pricing for nearly all employees. In addition, *Access MIT* increases the level of subsidy offered by MIT for transit passes. Use of local MBTA services will be 100% subsidized and the subsidy for commuter rail passes will be increased to about 60% of the average commuter rail zone pass. And a 50% subsidy of parking at transit stations will also be introduced at the same time. The *Access MIT* program bundles daily parking pricing with effectively universal access to transit for employees, representing a pairing of TDM strategies that have been shown to be effective in producing shifts in employee mode share.

3 Mode Choice Trend Analysis

3.1 Introduction

This chapter investigates MIT commuting survey data and related data sets in order to identify trends in employee mode choice, employee demographic characteristics and transportation benefits selection from 2004 to 2014. The commuting survey provides data on thousands of employees' and students' personal characteristics and behaviors, including reported information on commuting mode choice. Per regulations enforced by the State of Massachusetts and the City of Cambridge, the Institute is required to achieve a response rate of at least 50% for the commuting surveys and to report on the MIT community's commuting mode split. MIT uses the data collected in these surveys to study how employees and students travel to and from campus and to evaluate how well the Institute's transportation services are meeting the needs of its commuting population.

This research focuses specifically on MIT employees and does not analyze respondent data from populations such as students and contractors, who are likely to have very different commuting behaviors. Furthermore, employees represent the population within the MIT community that is most effectively targeted and most likely affected by TDM strategies implemented by the Institute. In the surveys analyzed in this thesis, the response rate among employees ranges from 47% to 58%. To judge how well the respondents represent the total MIT employee population and its corresponding mode split, the distribution describing respondents' purchases of parking permits and transit passes through the MIT Parking and Transportation Office are compared to that for all employees.

For each survey year, the sample of respondents over represents employees who purchase parking permits and/or transit passes and underrepresents employees buying neither a parking permit nor a transit pass. In the survey samples across years, the percentage of employees with MIT issued parking permits ranges from 3% to 5% higher than for the general employee population. The percentage of respondents who purchase a transit pass ranges from about 5% to 9% higher than for all employees. This may suggest that using survey response data will likely result in an underestimate of the use of active modes and overestimate the use of motorized modes (i.e. SOV, public transportation and carpool/vanpool) among the MIT employee population. The underrepresentation of employees with neither a parking permit nor a transit pass makes sense as these individuals are also the least likely to be invested in the transportation services offered by MIT. It is likely that many of the individuals choosing not to purchase parking or transit through MIT do so because they regularly commute to and from campus by walking and bicycling. However, a number of the employees who do not purchase parking or transit through MIT may also regularly commute to MIT by means of motorized modes. Some employees may commute to MIT by SOV and use on-street or non-MIT parking or they may be dropped off by non-MIT family members or friends. It is also likely that a number of these individuals use public transportation but do not purchase their passes through MIT, such as those employees that might buy a senior pass through the MBTA or ride transit on a pay-as-you-go basis using a personal Charlie Card.

The purpose of this analysis is to study trends describing mode choice and to determine the probable drivers of these trends. For most of the last two decades, MIT has been involved in a "nudging" of employee behavior, involving gradually increasing the cost of parking to employees and decreasing the cost of transit by increasing subsidies. At present, the annual subsidy for an annual parker is approximately $2,000, or 60% of the cost to MIT of providing a parking space. MIT subsidizes transit for employees by 50% of the market cost, resulting in an annual subsidy of about $300 to $2,200 per employee, depending on the transit pass they choose. Offerings range from local bus passes and LinkPasses serving the immediate Boston metro area to passes for commuter rail services to as far as southern Rhode Island. The average transit subsidy for employees purchasing monthly passes from MIT is approximately $50 per month. In the case of both the parking and transit benefits offered by MIT, pre-tax treatment involves a further subsidy. Using these TDM incentives, MIT's goals include being able to reduce the amount of campus space that must be designated for parking purposes rather than more productive classroom and lab space, to reduce parking subsidies and to advance the objectives of its "Walk the Talk" initiative.

This chapter uses the commuter survey data to study employee mode choice and employee characteristics across years, in order to investigate if there are any significant trends in these behavioral and demographic variables over the decade-long study period. First, this thesis analyzes patterns in mode choice, observing a decrease in the rate of SOV commuting and increase in the rates of use of public transportation and active modes. Next, observed patterns in the demographic variables are examined across years in order to determine if any significant shifts in employee demographics may possibly be driving this change in mode choice. If significant trends in demographic variables can be shown to relate to changes in mode choice, this chapter will have provided evidence that demographic changes have played a major role in affecting this change. Next, trends in employee purchase of parking permits and transit passes are examined to determine if transportation benefit offerings and pricing might relate to trends in mode share. Lastly, this chapter discusses whether or not it is likely there, in fact, exist causal relationships between the metrics describing mode choice, employee characteristics and transportation benefits selection.

3.2 Employee Mode Choice

This thesis uses two variables to describe MIT employee commuting behavior, a categorical variable indicating mode choice and a calculated ratio of relative parking demand. The next sections describe these variables and analyze them across years.

3.2.1 Mode Choice

This section investigates patterns characterizing mode choice for MIT employees from 2004 to 2014. Mode choice is determined using the travel diary (a section in which respondents are asked to report their method of traveling to and from MIT for a sample week, Monday through Sunday) and reported primary mode in the surveys. These fields are compared and combined in order to categorize respondents into the following categories: SOV, public transportation, active mode and carpool/vanpool/private shuttle. Employees who report a given primary mode and indicate exclusive or near exclusive use of that mode in the travel diary are classified into one of these mode choice categories, and employees indicating differences between their reported primary mode and travel diary or within their travel diary entries are considered to be multi-modal. Respondents indicating multi-modal behavior are fractionalized appropriately among the four mode choice categories. For observations characterized by absent or insufficient travel diary and write-in data, this determination cannot be made, affecting a high of 5% of observations in the 2006 survey to a minimum of 1% in 2014. Table 3-1 shows the size of the samples of survey respondents for whom mode choice can be reasonably determined.

Table 3-1: Size of sample for MIT employees reporting mode choice for years 2004 to 2014

Survey year	Employees reporting mode choice	% of all employee respondents
2004	3,473	98
2006	4,505	95
2008	4,949	98
2010	4,816	98
2012	5,287	99
2014	5,918	99

Figure 3-1 illustrates the percent of employee respondents using each mode (SOV, public transportation, active mode and carpool/vanpool/private shuttle) for each survey.

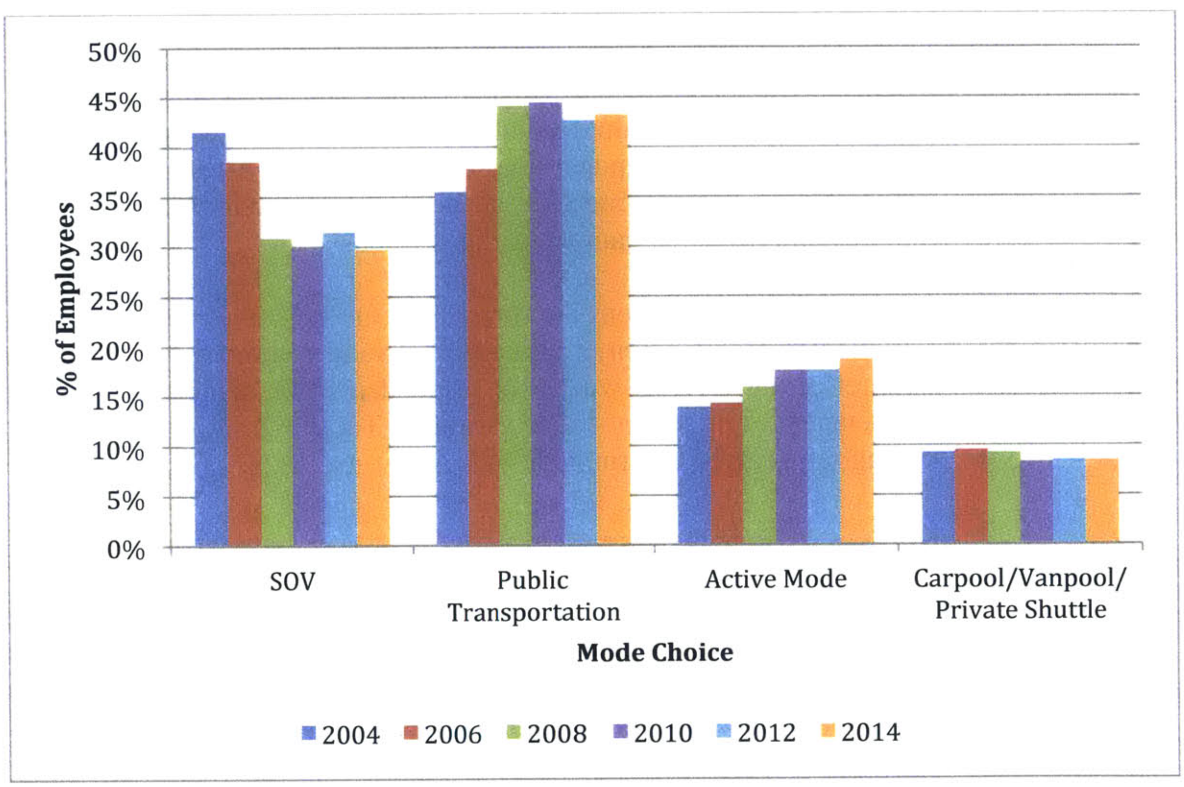


Figure 3-1: Percent of employee respondents by mode choice for years 2004 to 2014

Figure 3-1 suggests a general trend of decreasing drive alone commuting and an increasing use of public transportation and active modes from 2004 to 2014. An approximately 12% decrease in SOV mode share is observed over the study period. There are increases of approximately 8% and 5% in public transportation and active travel mode shares, respectively. Use of carpool, vanpool and private shuttle services is seen to decrease by about one percentage point.

This analysis suggests notable changes in the commuting behaviors of MIT employees over time. Decreases in SOV commuters and increases in public transportation riders and active mode commuters have substantial implications in the context of the Institute's goals for its TDM programs: managing parking demand - in order to reduce the amount of land required to provide parking and avoid the cost of unneeded leased spaces - and mitigating MIT's contribution to greenhouse gas emissions, air pollution and congestion on local roadways. In addition, the growth in the use of active modes has positive effects on employee health. In studying these distributions, however, it is important to consider that the employee population at MIT is growing over this same time period, so percent decreases in drive alone commuting do not necessarily directly translate into decreased demand for parking, as measured by the absolute number of spaces used. The end of this chapter estimates parking demand across years in absolute numbers. The next section of this chapter examines another variable describing mode choice, the parking ratio.

3.2.2 Parking Ratio

The second mode share metric, called the "parking ratio" in this thesis, is a measure of a given employee's use of campus parking divided by the number of days they report a commute trip to MIT. The parking ratio ranges from zero to one. Higher values indicate a high frequency of driving alone to MIT campus, while lower values point to use of carpooling among employees, which uses parking more efficiently, or to modes that do not require on-campus parking all together. This metric serves as a quantitative measure of mode choice explicitly in terms of the employee's corresponding demand for an on-campus parking space.

The parking ratio is determined using data from the travel diary in the survey and is calculated for all observations in which there is indication of at least three valid commutes. This is done to eliminate travel diary data reflecting atypical weeks for respondents (i.e. being out sick, out of town for business or a conference, or on sabbatical or vacation). Table 3-2 shows the size of the sample for which the parking ratio can be determined.

Table 3-2: Size of sample for MIT employees reporting 3+ work commutes for years 2004 to 2014

Survey year	Employees reporting 3+ work commutes	% of all employee respondents
2004	3,420	96
2006	4,423	94
2008	4,573	91
2010	4,474	91
2012	4,909	92
2014	5,441	91

Next, this section investigates trends in the parking ratio over time. Table 3-3 shows the mean and standard deviation of the parking ratio for all surveys.

Table 3-3: Calculated mean and standard deviation for parking ratio for years 2004 to 2014

Survey year	Mean	Standard Deviation
2004	0.46	0.45
2006	0.43	0.45
2008	0.35	0.43
2010	0.34	0.43
2012	0.36	0.43
2014	0.33	0.43

Table 3-3 illustrates a trend of decreasing values of the parking ratio, suggesting that employees are increasingly moving toward use of non-SOV modes. The trend in the means of the parking ratio very closely resembles the pattern observed in the percent of employees for whom mode choice is SOV in Figure 3-1. The standard deviations point to significant spread in the values of the parking ratio found in the data indicating that these distributions are not well centered around the average.

These calculations reaffirm the findings detailed in Section 3.2.1, which identify a general trend in employee mode choice away from SOV commuting from 2004 to 2014. The implications of this pattern are similar to those discussed in the previous section: a percentage decrease in parking demand, reductions in the emissions of greenhouse gases and air pollutants, mitigation of MIT's contribution to local roadway congestion and increased employee health. The next sections of this chapter examine variables measuring demographic features commonly shown to be predictive of employee mode choice in transportation studies and models. This analysis of employee mode choice and the parking ratio provides a basic understanding of general trends in commuting behaviors against which to compare and contrast possible trends observed in these other metrics.

3.3 Home Location

Employee home location represents a significant predictor of employee commuting behavior. Transportation studies and models show factors such as travel time and availability of transportation options to be among the primary factors influencing travelers' choice of mode, and these factors are largely dictated by place of residence. This thesis uses three metrics to measure employee home location: distance to MIT, access to an MBTA bus stop and access to an MBTA rapid transit station. These variables serve as proxy measurements for travel time and the availability of transportation options other than SOV commuting. The next sections discuss these metrics and examine them across years.

3.3.1 Distance to MIT

The distance between home location and place of work is likely correlated with travel time. Additionally, the distance between home and work locations is closely related to the likelihood of use of an active mode for these trips (walking, biking and running). As the distance between trip origin and destination grows larger, travelers increasingly favor motorized modes such as public and private transportation providers, and especially automobiles. In the case of this thesis, the distance between employee's home location and MIT is also likely to be correlated with the availability of public and private transportation services. Located in southern Cambridge, MIT is geographically near to the center of the greater Boston area, which is characterized by an array of public and private transportation options. As the distance between an employee's home and MIT increases, it is likely that these options grow sparser and their corresponding travel times grow longer, making them less attractive methods of travel.

This section provides an overview of patterns in the home to MIT distances for Institute employees over the study period. Table 3-4 summarizes the availability of home location data for MIT employees and indicates the precision of these data for years 2004 to 2014.

Table 3-4: Size of sample for MIT employee respondents with valid home location data for years 2004 to 2014

Survey year	Employees w/ home location data	% of all employee respondents	Precision
2004	3,221	91	Zip code
2006	3,098	66	Nearest intersection
2008	3,911	78	Nearest intersection
2010	No data	n/a	n/a
2012	5,156	96	Census block
2014	5,655	95	Census block

Table 3-4 shows a wide range of response rates, lowest in 2006 and 2008 and highest in 2012 and 2014. The commuting survey included a question asking employees to describe the location of their homes using postal code in 2004, then postal code and nearest street intersection in 2006 and 2008. In 2010, this question was removed from the survey, but starting in 2012, the MIT Office of the Provost attaches census block geographic identification data to the surveys indicating employees' home locations. The lower response rates observed in 2006 and 2008 probably reflect some employees' reluctance to volunteer relatively sensitive information. The precision with which employees' place of residence can be mapped also varies significantly. When calculating the distance between an employee's home and MIT[2], the extra data provided in years 2006, 2008, 2012 and 2014 represent a significant improvement in the quality of this estimate over use of only more aggregate zip code data, as was available in 2004.

Distributions in the calculated distances from home to MIT are determined for years 2004 to 2008 and 2012 to 2014 in order to detect any shifts in employee home location over the study period. For 2004, the distribution of these distances demonstrates significant irregularities compared to distributions for the other years. This is judged to be attributable to the imprecise nature of the zip code data. Figure 3-2 presents these distributions for years 2006 and 2014.

Figure 3-2 demonstrates slight differences in shape likely attributable to the different mapping methods used for 2006 and 2008 versus 2012 and 2014, but shows a common pattern of most employees living close to MIT. Table 3-5 presents a summary of statistics describing the distributions of employees' home to MIT distances.

Table 3-5: Descriptive statistics for distance (in miles) between home and MIT for employees for years 2006, 2008, 2012 and 2014

Survey Year	Mean	25th Percentile	Median	75th Percentile
2006	8.15	2.09	4.65	10.13
2008	7.85	2.00	4.26	9.37
2012	8.75	2.09	4.84	10.54
2014	8.01	2.07	4.58	9.70

The mean and quartile calculations may suggest a slight trend of MIT employees living closer to the Institute on average. Within the survey pairs for which the same mapping methods are used, there are observed decreases in the mean and quartile values from the earlier year to the more recent year, but it is difficult to conclude that any significant trend exists. Across years, these statistics indicate that a quarter of the employee population within roughly two miles of main campus. In addition, more than half of MIT employees are shown to live within five miles of the Institute. At these distances, active modes and public transportation likely represent realistic transportation options for much of MIT's employee population. A two-mile radius around MIT, for example, encompasses parts of Cambridge, Boston and Somerville, which are characterized by relatively available public transportation services and quality infrastructure for active modes, including sidewalks and bike lanes and bike paths. Employees living in places of residence located farther away from MIT not only likely face increased travel times, but also likely do not have a comparable level of access to quality public transportation services and infrastructure to accommodate active modes for their work journeys.

[2] For this calculation, the geographic location of MIT is represented by Building 7, at 77 Massachusetts Avenue.

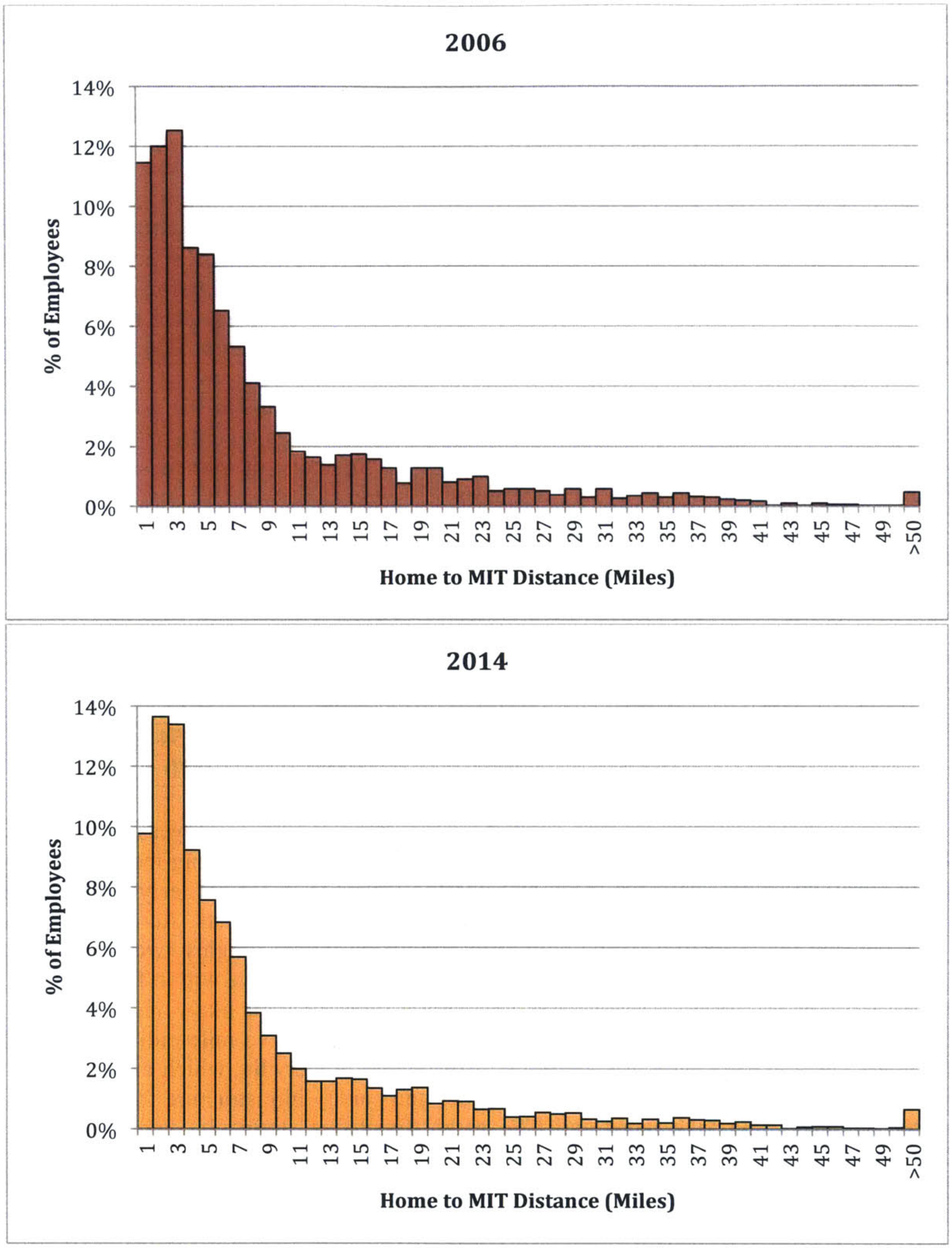


Figure 3-2: Employee home distance to MIT for years 2006 and 2014

To study the relationship between home location and mode choice, the values of the parking ratio are regressed against employees' home to MIT distance data. Figure 3-3 shows a scatterplot describing the relationship of these two variables for 2006, 2008, 2012 and 2014. The best-fit line is restricted here to have an intercept of zero.

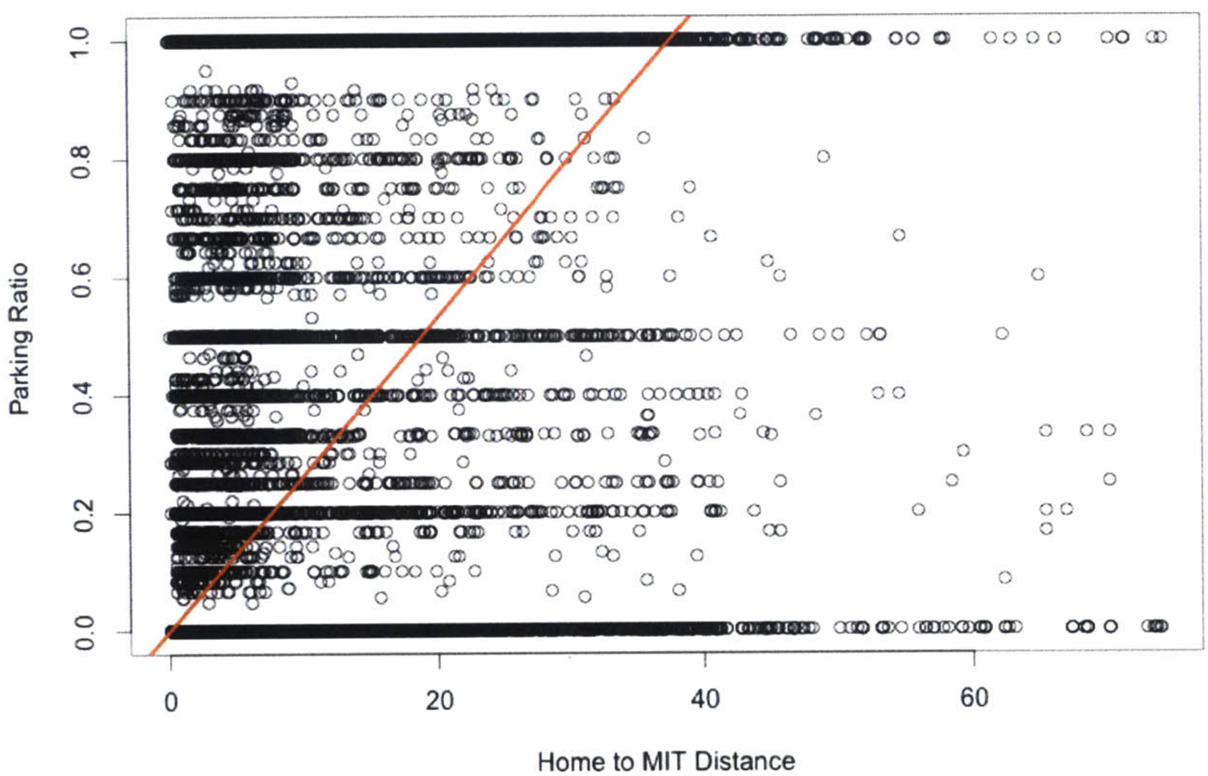


Figure 3-3: Relationship between home to MIT distance and parking ratio for 2006, 2008, 2012 and 2014

Table 3-6 shows the results of a regression relating the parking ratio and home to MIT distance for 2006, 2014 and all years. In each linear model, the intercept is set to be equal to zero, as in Figure 3-3, above. The "all years" model corresponds exactly to the best-fit line shown in Figure 3-3.

The linear model shown in Table 3-6 demonstrates a positive relationship between home to MIT distance and the value of the parking ratio. For each mile increase in the distance between an employee's home and MIT, the model predicts a 0.02 to 0.03 increase in the value of the parking ratio. Assuming a five-day workweek, this roughly corresponds to an employee driving alone and parking on campus one more day per week for each seven to ten miles in distance they live from MIT. The R-squared values, however, indicate that the model explains only about 30% of the total variation in the data.

Table 3-6: Parking ratio related to commuting distance

	2006	2014	All years^
Home to MIT distance	0.029***	0.024***	0.023***
	(0.001)	(0.001)	(0.000)
R-squared	0.338	0.287	0.283
Adjusted R-squared	0.338	0.287	0.283
No. observations	2,957	5,176	16,462

^ 2006, 2008, 2012 and 2014
Standard errors are reported in parentheses
*, **, *** indicate significance at the 90%, 95% and 99% levels, respectively

From the analysis presented in this section, this research cannot conclude that there exists a significant trend of employees moving closer to or farther from campus over the studied time period. Greater distances between an employee's home and MIT are determined, however, to be correlated with higher values of the parking ratio variable, suggesting increased use of SOV commuting. This finding is likely due to many of the factors already discussed in this chapter: home proximity to MIT makes active modes a more attractive choice and is likely correlated with better access to public transportation services, whereas for those living far from campus, the opposite is true. The next sections provide a more detailed analysis of trends concerning employee home location in the context of the accessibility of public transportation services.

3.3.2 Access to MBTA Bus Services

This section introduces a metric used to evaluate the accessibility of public transportation bus services given the employee's home location. In addition to overall travel time, the degree of access to public transportation services represents a significant factor influencing mode choice. This variable indicates whether or not an employee lives within a quarter mile radius of one or more MBTA bus stops, a distance commonly used by transportation planners and modelers to represent a reasonable walking distance to bus services. Table 3-7 shows the percentage of employees with quality access to bus services, that is, live within 0.25 miles of at least one MBTA bus stop. Because there has been no significant expansion of MBTA bus services over the time period represented by these data, the location of bus stops is taken to be constant across years.

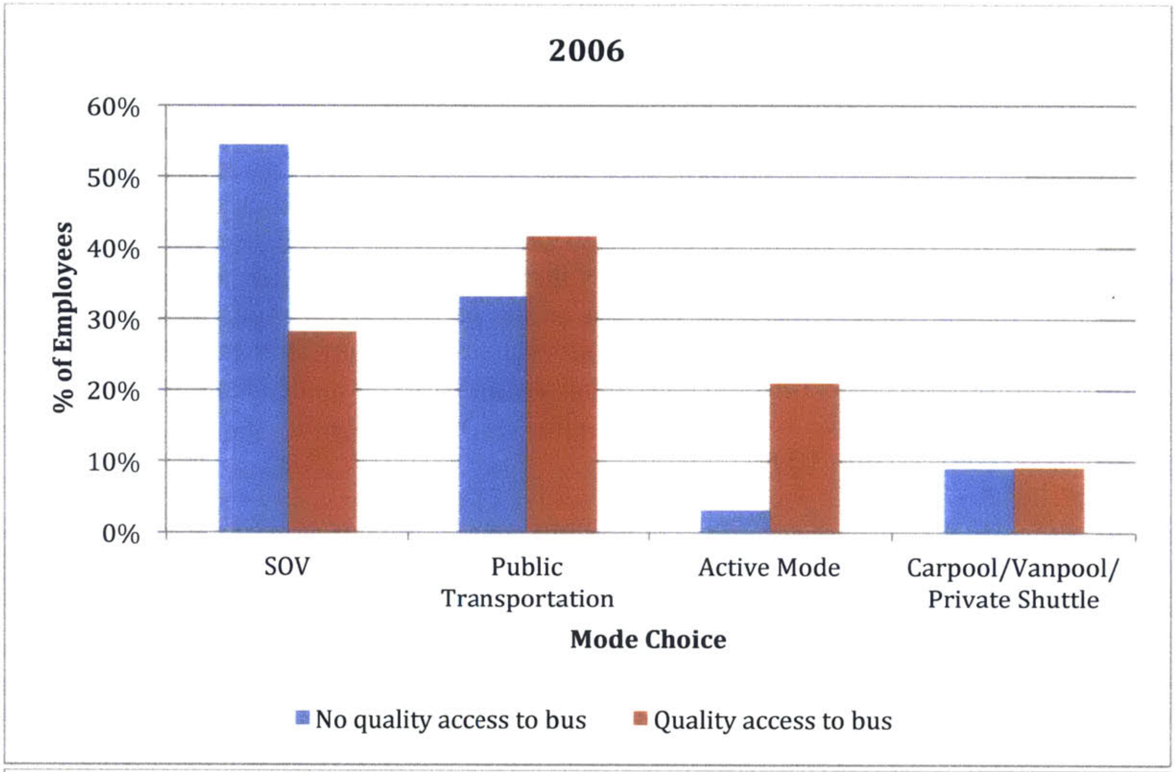
Table 3-7: Percent of employees with quality access to MBTA bus services for years 2006, 2008, 2012 and 2014

Survey Year	% of Employees w/ Quality Access to Bus
2006	70.0
2008	71.5
2012	63.6
2014	65.1

Table 3-7 suggests that most of the MIT employee population lives within reasonable walking distance to one or more MBTA bus stops. The difference in the percentage of employees living within a quarter mile of a bus stop in 2006 and 2008 versus 2012 and 2014 is likely due to the difference in mapping methods. Using nearest intersection data as a proxy for home location assumes the employee resides at the indicated intersection, and therefore likely closer to local bus stops, which are most often located at street intersections. Census block data estimates home locations at the centroids of census blocks based on boundaries established by the US Census Bureau, which results in home location estimates that are more independent of the road network. Table 3-7 may indicate a very marginal increase in the percentage of employees living in areas characterized by quality access to MBTA bus services, but it is difficult to conclude from the data shown. Figure 3-4 below, illustrates the relationship between mode share and access to bus services, showing mode choice for employees with and without quality access to bus services. Bars of the same color total to 100%.

Figure 3-4 suggests that employees who live within a quarter mile of at least one MBTA bus stop are more likely than their counterparts to use public transportation or active travel for their commute trips. In 2006, 63% of employees with quality access to a bus stop used public transportation or active travel, and, by 2014, this percentage increases to 70%. For those employees without quality access to bus, 36% and 45% use either public transportation or active modes in 2006 and 2014, respectively. In percentage terms, employees without a bus stop nearby are about twice as likely to be SOV commuters than those who live close to a bus stop.

The observed differences in mode share for employees with and without quality access to bus services across year are likely due to a number of factors. First, easy walking accessibility to a bus stop is likely to make public transportation a more attractive option than for those who do not benefit from such close access. Additionally, the MBTA's bus network centers most of its services in most notably, Boston and Cambridge, and immediately surrounding towns. This means that those employees who live close to a bus stop are also likely to live closer to MIT on average than those employees who do not live close to a bus stop. The average distance from home to MIT for employees within a quarter mile of a bus stop is about 3.75 to 4 miles, compared to an average of 16 to 18 miles for those employees outside of the quarter mile buffer. This likely explains why much higher percentages of employees who are close to bus stops use active modes compared to those who are not close to bus stops across years. The next section evaluates the effect of access to rapid transit services on mode choice and compares the results to these findings.



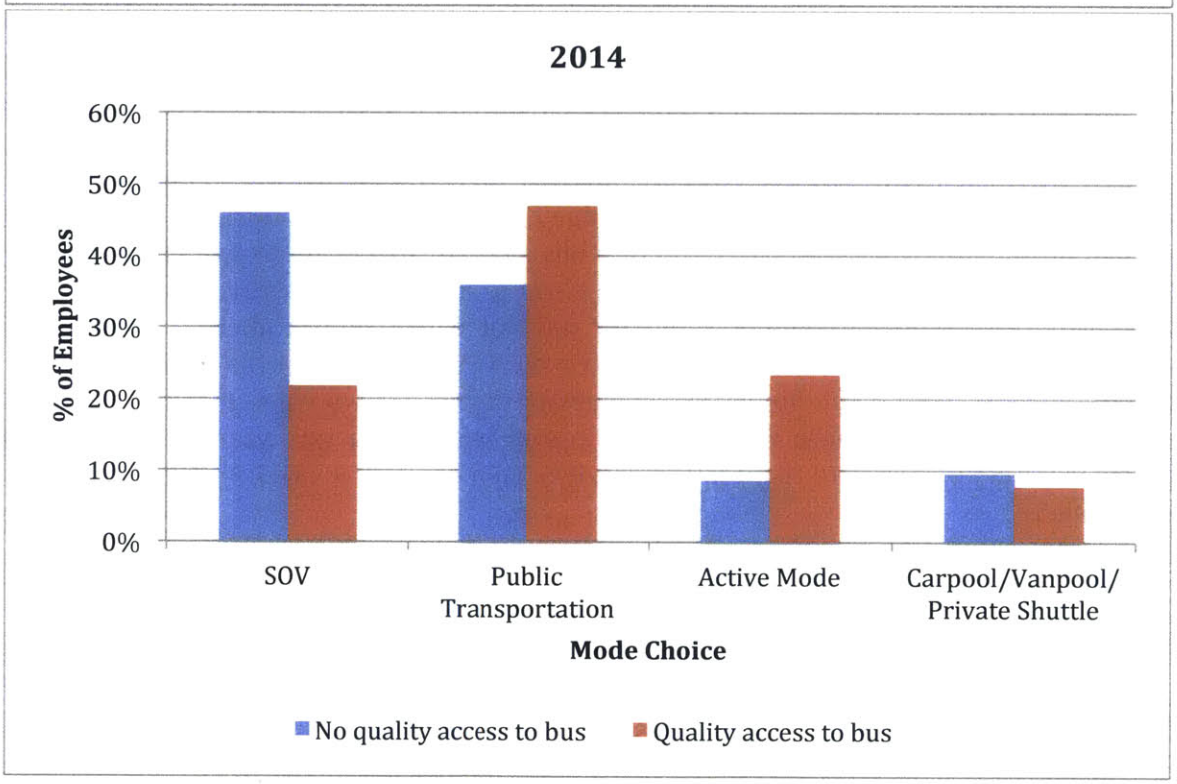


Figure 3-4: Mode choice for MIT employees with and without quality access to MBTA bus services for years 2006 and 2014

3.3.3 Access to MBTA Rapid Transit Services

This section evaluates a measure similar to the variable for access to bus services introduced in the previous section. This variable is structured similarly, indicating whether or not an individual lives within a third of a mile of an MBTA rapid transit station. Because of the faster speeds and greater service frequencies, planners and modelers generally assume people are willing to walk slightly farther to access rapid transit services than for bus services. Table 3-8 shows the percentage of MIT employees living within one third of a mile of one or more rapid transit stations. Most of the rapid transit network is well served by bus services as well. Approximately 95% of those employees living in places with quality access to subway and light rail services have quality access to bus services too, according to the metric introduced in Section 3.3.2.

Table 3-8: Percent of employees with quality access to MBTA rapid transit services for years 2006, 2008, 2012 and 2014

Survey Year	% of Employees w/ Quality Access to Rapid Transit
2006	22.2
2008	23.1
2012	19.1
2014	20.7

Table 3-8 shows that about one fifth of MIT employees live within easy walking access of one or more MBTA rapid transit stations. The determination of any trends in employee home location in this context is complicated by the different mapping methods used in 2006 and 2008 versus 2012 and 2014, as was the case for measuring access to bus. Figure 3-5 demonstrates the relationship between access to one or more MBTA rapid transit stations and mode choice.

Figure 3-5 indicates that the majority of MIT employees who live close to at least one rapid transit station commute by public transportation. Approximately 78% and 84% of employees living within a third of a mile of a rapid transit station commuted to MIT by means of public transportation or active modes in 2006 and 2014, respectively. For comparison, only 48% and 56% of employees without quality access to rapid transit commuted by means of public transportation or active modes in 2006 and 2014, respectively. Employees who live near at least one rapid transit station show strong preference for more sustainable modes (and especially public transportation), even stronger than that demonstrated for employees who live less than a quarter mile from a bus stop. The percentages of employees who live within a third of a mile from a rapid transit station and use transit and active modes are about 10% and 5% greater than for employees who live close to a bus stop, respectively. Employees who live close to bus or rapid transit services are both more likely to choose more sustainable modes, but this suggests that proximity to rapid transit more strongly influences MIT employee mode choice.

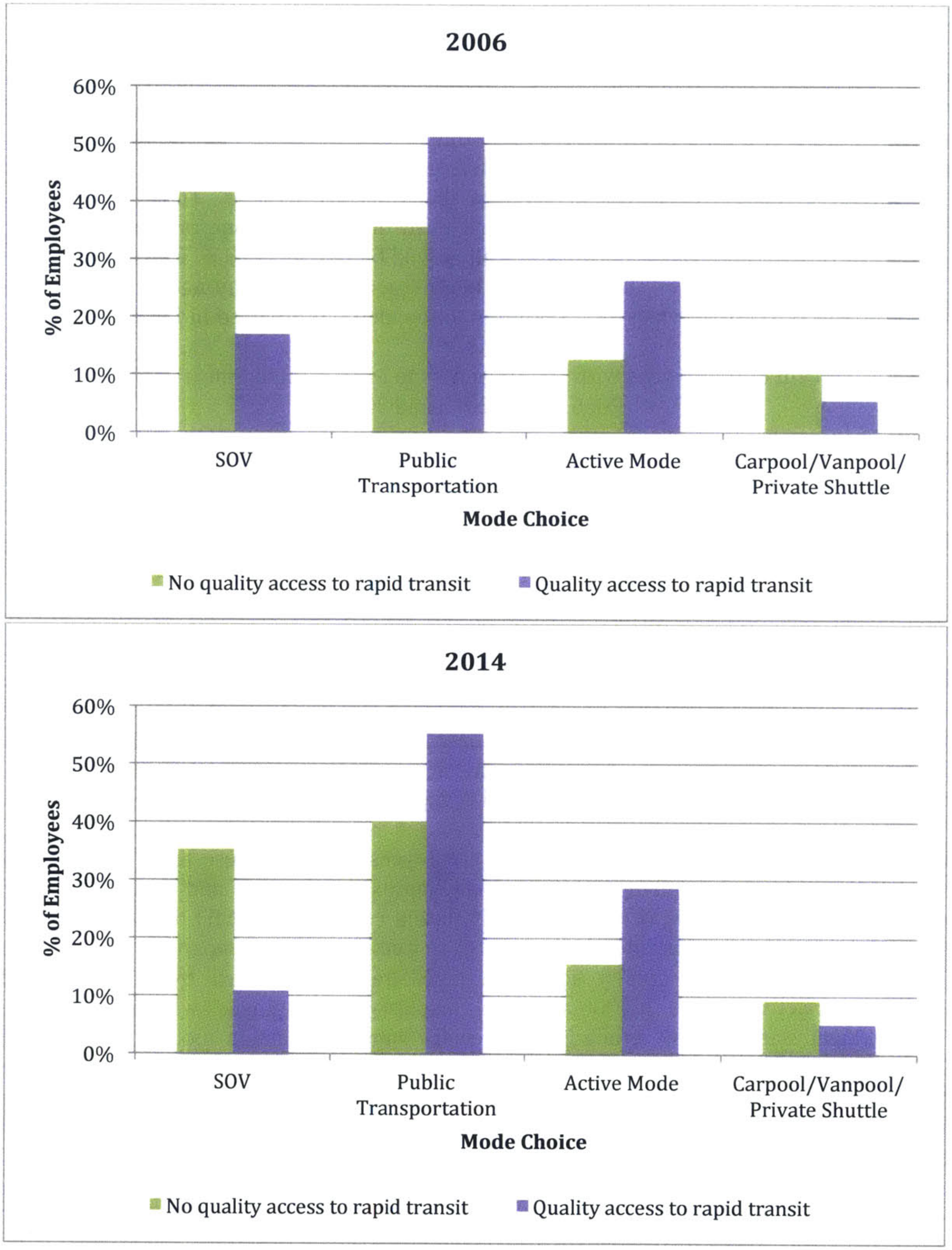


Figure 3-5: Mode choice for MIT employees with and without quality access to MBTA rapid transit services for years 2006 and 2014

Employees who live close to a rapid transit station have better access to the subway, light rail and bus rapid transit services operated by the MBTA, making them a more viable option for their commute. In addition, those living within a third of a mile buffer of the MBTA's rapid transit network are also located closer to MIT, on average. Employees with quality access to rapid transit live an average of about 2.25 miles from the Institute across years, while those without quality access to rapid transit live 9.5 to 10 miles from MIT on average. This likely explains the higher rates of use of active modes among employees who live close to these stations. In this section and last, this thesis also finds that rapid transit seems to attract a greater percentage of public transit riders than bus. Some of this effect may be attributable to the shorter distance from home to MIT, on average, for employees with quality access to rapid transit compared to those with quality access to bus (~2.25 miles vs. ~3.75 miles). Much of this may also be due to a number of other factors, however, including generally higher service frequencies and travel speeds for rapid transit. Personal preferences also play an important role. For example, many users associate rapid transit with improved levels of comfort. Rapid transit may be less crowded and be characterized by less of the unexpected, jerky stop-and-go behavior than for buses, which must deal with the unpredictability of roadway traffic.

3.3.4 Mapping Mode Choice by Home Location

This section presents visualizations of the relationship between home location and employee mode choice. Figure 3-6 and Figure 3-7 show the distribution of MIT employees by home location and by mode within the approximate area of the MBTA's rapid transit network (shown in black) for 2006 and 2014, respectively. Major highways are shown in grey, and an orange circle designates the location of 77 Massachusetts Avenue on MIT main campus. Pie charts illustrate the mode share for all employees living within a census block. The size of the pie is proportional to the total number of employees living in the census block. For both figures, approximately 75% of MIT employees live within the area shown. For home locations beyond the area shown here, SOV is the predominant mode choice with about 55% of those longer distance commuters driving alone to MIT on a regular basis in 2006, and 50% in 2014.

Figure 3-6 and 3-7 show some strong patterns in the distribution of employees by home location and mode choice. In both maps, there is a significant concentration of employees in the census blocks nearest to MIT and Cambridge. The maps also illustrate strong spatial relationships for mode choice. Those employees living closest to MIT commute primarily by means of active modes. Employees living further from MIT seem to favor motorized modes. At intermediate distances and near to the MBTA's rapid transit network, there is evidence of significant rates of public transportation use. At greater distances, however, employees commute by means of SOV with greater frequency.

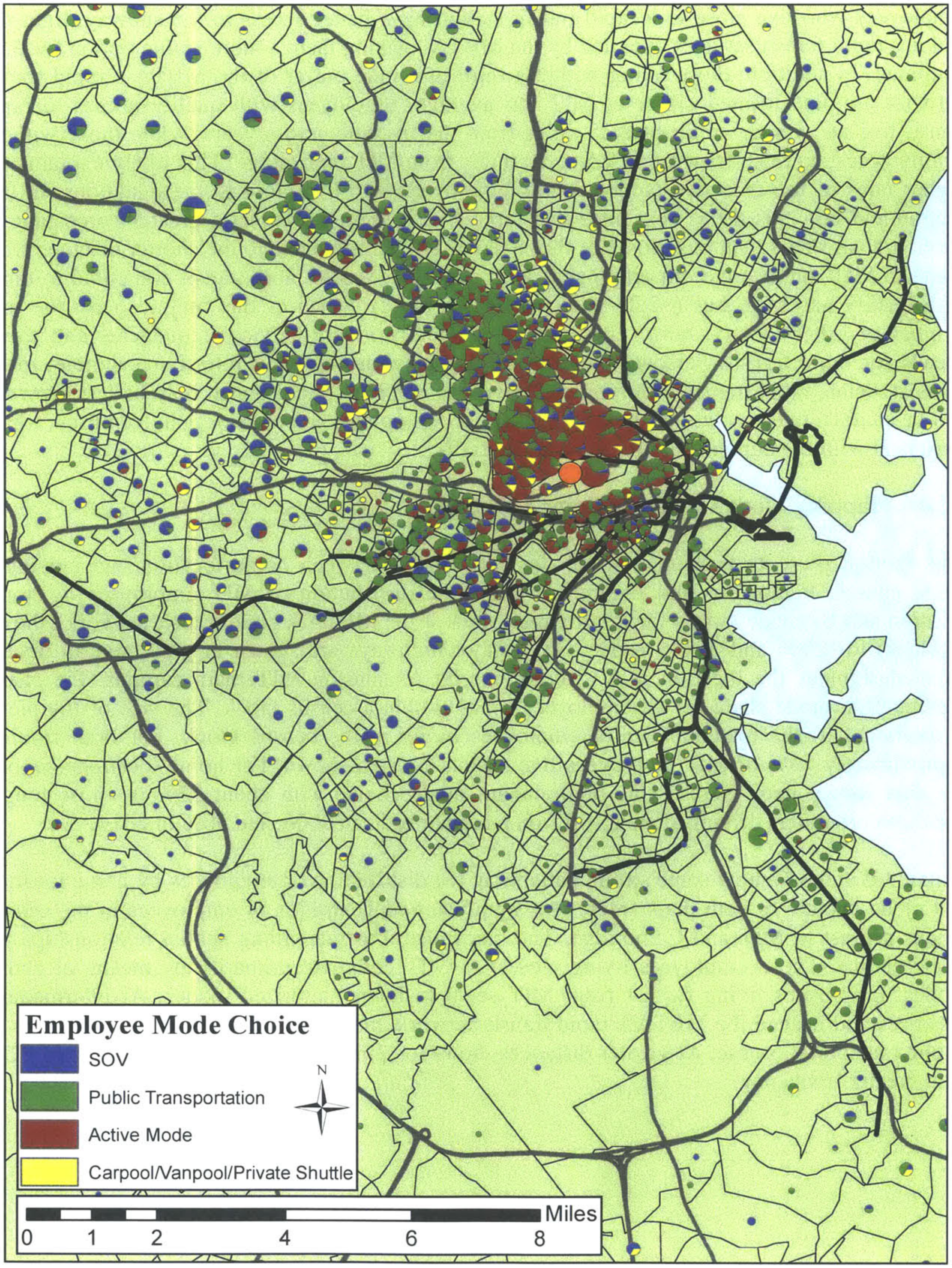


Figure 3-6: Relationship between home location and mode choice for 2006

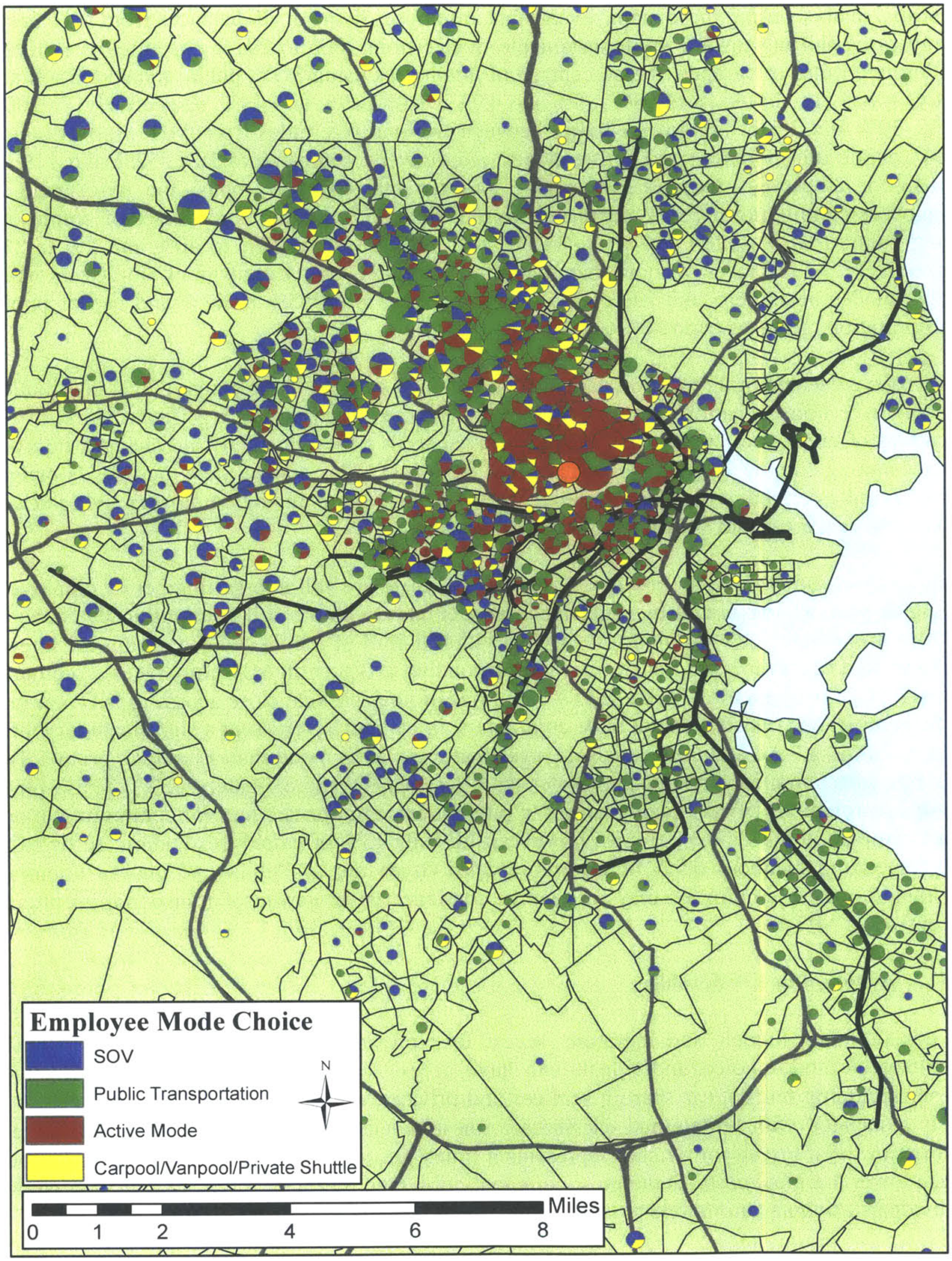


Figure 3-7: Relationship between home location and mode choice for 2014

A spatial analysis using these maps reveals that employees living at all distances from MIT are in many cases shifting toward more sustainable modes from 2006 to 2014. For employees living within two miles of campus, the percentage of employees using SOV, public transportation and active travel has shifted from 14%, 35% and 45% to 10%, 37% and 48%, respectively. In 2006, 34%, 50% and 7% of employees living between two and five miles from MIT used primarily SOV, public transportation and active modes, respectively, compared to 28%, 52% and 11% in 2014. For employees living between five and ten miles from campus, the percentage of employees commuting by SOV decreases from 51% to 45% and the percentages of employees using public transportation and active modes both increase, from 35% to 40% and 2% to 3%, respectively. At distances of more than ten miles from MIT, the percentage of employees using active modes nears zero, but use of SOV still decreases from 55% to 47% and use of public transportation increases from 36% to 43%.

The maps presented in this section demonstrate common patterns in the geographical distribution of employee home locations across years. Despite no evidence of any significant shifts in the locations of employees' places of residence, this analysis points to significant changes in mode choice among employees living at all distances from MIT. This may suggest that MIT's nudges have served as effective measures in reducing SOV mode share among employees living across many different areas and not only those closest to campus.

This analysis, however, also provides evidence that there are still a large number of employees living in areas characterized by high transit accessibility who are still commuting by SOV. In 2014, for example, 11% of employees living within a third of a mile of a station on the Green, Orange, Red or Silver rapid transit lines (corresponding to 3% of all MIT employees) commuted to MIT by SOV regularly. These MBTA rapid transit lines provide close access to MIT campus with, at most, one transfer. These SOV commuters, in particular, represent a significant target for future "nudging." An additional analysis investigates the 2014 mode shares in block groups with a public transportation mode share greater than the median (approximately 42%). These block groups represent areas with quality access to public transportation services for commuting to and from campus. In these block groups, however, still fully 13% of employees commuted by SOV (corresponding to about 6.5% of all employees). Given the availability of quality commute alternatives, these employees may respond to continued development of transportation pricing incentives at MIT.

3.4 Automobile Ownership

In transportation models and literature, access to a private vehicle is an extensively studied predictor of mode choice. Individuals can have access to automobiles through a number of means including rentals, car sharing services and private ownership. Given the higher marginal costs associated with rentals and car sharing, these services are generally used for relatively infrequent trips. Private ownership represents a much greater sunk cost than these services but, given lower marginal costs, is the most commonly observed means of access to a vehicle among individuals using an automobile to make regular trips, such as work trips.

Automobile ownership represents an important predictor of mode choice because convenient and low-marginal cost access to a personal vehicle has significant influence on trip characteristics such as travel time and comfort. Individuals tend to value time and comfort highly, and personal vehicles are popularly considered to outperform other modes (public transportation, active travel and ride sharing) on these metrics. Vehicle owners are generally more likely to elect to drive because of the faster travel and ample personal space that this choice usually provides. For individuals that do not own personal automobiles, however, gaining access to a car is characterized by a much greater cost (both monetary and time cost), meaning these individuals are more likely to choose other options from those that may be accessible. In an urban environment like that of the greater Boston area, these options include public transportation services and private transportation services such as commuter bus operators and ride sharing services such as carpooling, vanpooling, and even Uber and Lyft.

This section investigates data on automobile ownership among MIT employees in order to observe any trend over the study period. To measure automobile ownership, this thesis uses a ratio of the number of automobiles an employee's household owns to the number of individuals in their household with a valid driver's license. The commuting survey featured questions into both of these values in years 2006 to 2014, but not in 2004. This thesis refers to this ratio as the "automobile ownership ratio." A ratio value of zero indicates that the employee has no access to a private automobile, while a ratio of one or greater means that the employee's household owns at least one car for every driver in the household. Table 3-9 shows the total number of respondents reporting both fields in the survey necessary to calculate the automobile ownership ratio.

Table 3-9: Size of sample of MIT employees with a calculated automobile ownership ratio for years 2006 to 2014

Survey year	Employees reporting HH autos and drivers	% of all employee respondents
2006	4,452	94
2008	4,523	90
2010	4,468	91
2012	4,962	93
2014	5,633	94

Table 3-10 summarizes the mean and standard deviation in the values of the automobile ownership ratio across years.

Table 3-10: Descriptive statistics for the automobile ownership ratio for years 2006 to 2014

Survey year	Mean	Standard Deviation
2006	0.789	0.418
2008	0.750	0.431
2010	0.743	0.437
2012	0.743	0.431
2014	0.730	0.435

The calculated averages for 2006 to 2014 suggest a general decrease in automobile ownership among MIT employees. The distributions in values of the automobile ownership ratio for employees are characterized by notable spread. To better visualize this trend across years, Figure 3-8 shows the percentage of employees with an automobile ownership ratio equal to zero, between zero and one, equal to one, and greater than one.

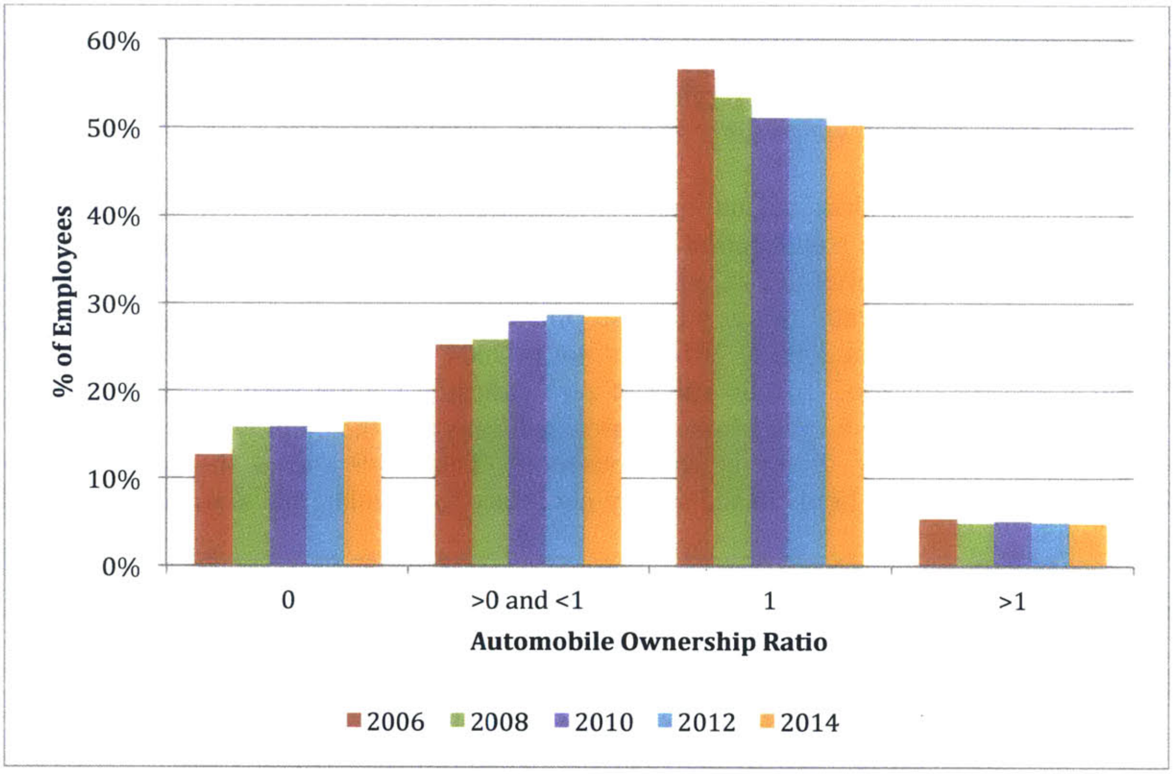


Figure 3-8: Percent of employees by automobile ownership ratio for years 2006 to 2014

From 2006 to 2014, there is growth in the percentage of employees with an automobile ownership ratio of less than one. Over this time period, there are approximately 4% and 3% increases in carless employee households and employee with a ratio between zero and one, respectively. There is a similar decline in the percentage of employees with one or more automobiles per driver in the household. Between 2006 and 2014, there is an observed nearly 6.5% decrease in the percent of surveyed employees with a ratio equal to one and an approximately half-point decrease in employees with a ratio greater than one.

Visual inspection of the distributions of the automobile ownership ratio across years indicates that a greater percentage of MIT employees are choosing to maintain lower rates of car ownership today than about ten years ago. While not captured in the analysis, this trend may be driven by a number of factors, such as the costs associated with owning, operating and parking a car, home location, availability of other modes or transport and personal preferences. Next, this section investigates the relationship between automobile ownership and mode choice. Figure 3-9 shows a scatterplot describing these two variables.

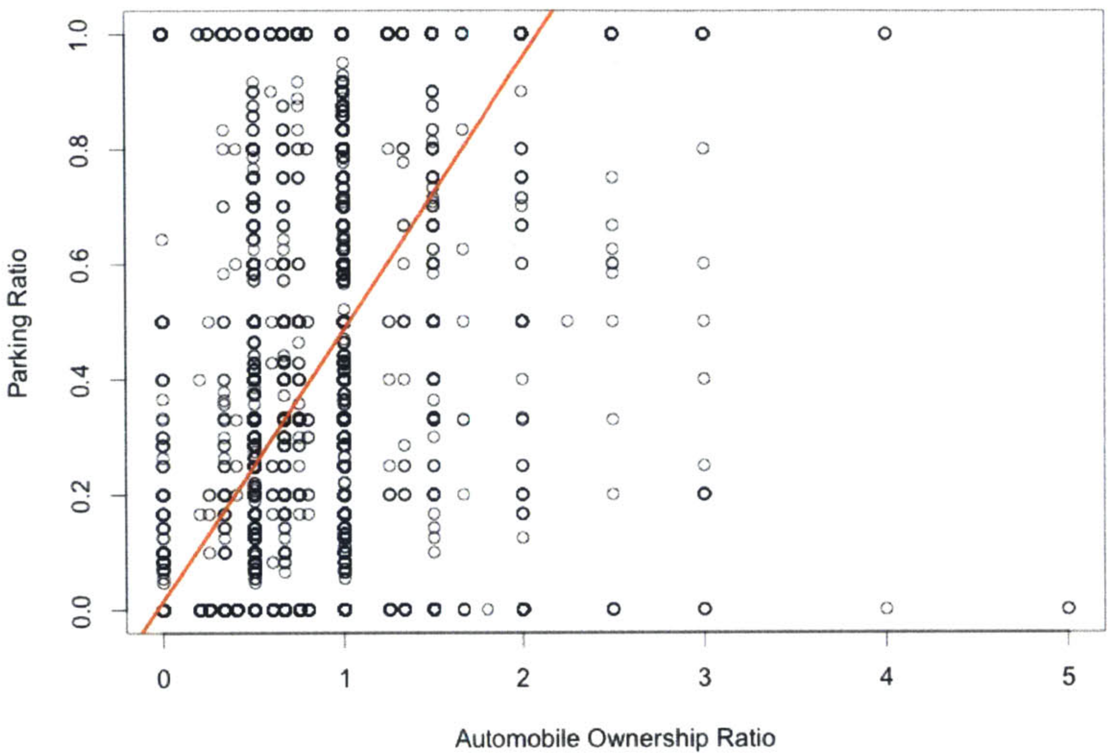


Figure 3-9: Relationship between automobile ownership ratio and parking ratio for survey years 2006 to 2014

Table 3-11 provides the results of a regression analysis for years 2006, 2014 and all years for which car ownership data is available.

Table 3-11: Parking ratio related to automobile ownership

	2006	2014	All years^
(Intercept)	0.035***	0.007	0.016***
	(0.013)	(0.010)	(0.005)
Auto ownership ratio	0.503***	0.462***	0.471***
	(0.014)	(0.012)	(0.006)
R-squared	0.223	0.215	0.218
Adjusted R-squared	0.223	0.214	0.218
No. observations	4,258	5,227	22,527

^ 2006 to 2014
Standard errors are reported in parentheses
*, **, *** indicate significance at the 90%, 95% and 99% levels, respectively

The linear model shown in Table 3-11 and Figure 3-9 illustrates a positive relationship between automobile ownership and the value of the parking ratio. The magnitude of the model coefficients suggests that car ownership has very significant impact on mode choice. According to the model, an employee who lives in a household with two drivers and two cars is expected to commute by SOV 25% more than an employee who lives in a household with only one car shared between two licensed drivers. However, the R-squared values indicate that the model explains only about 20% of the variation in the data, so the predictive value of this simple linear model is pretty weak.

This section demonstrates a slight trend toward decreasing levels of car ownership among MIT employees. There also exists a relationship between values in the automobile ownership ratio and parking ratio, suggesting that those with greater access to a personal car, on average, drive to and park on MIT campus more often. Given this relationship, a decreasing trend in automobile ownership is expected to have a significant impact on the demand for campus parking and other areas in which the Institute has a stated interest: MIT's contributions to climate change, air pollution and local roadway congestion. However, the decision to purchase an automobile is driven by individuals' commuting distance, expectations of their own behaviors (including mode choice) and personal preferences, so it is difficult to judge the impact of car ownership on mode choice independently.

3.5 Age and MIT Work Experience

In addition to the biennial commuter survey data, this thesis incorporates a number of additional datasets to determine trends in employee characteristics across years. These data are matched to the survey data where possible. For years 2010 and 2012, the MIT Office of the Provost has attached data on employees' ages to the corresponding commuting surveys. The office also maintains records of the month and year of hire for MIT staff, and these records were made available for survey years 2008 to 2014. These data and other datasets external to the survey presented later in the chapter may demonstrate additional trends in employee characteristics over time at the Institute. Age is commonly an important demographic predictor in mode choice models, and a measure of employees' time of employment at the Institute is also likely a factor influencing mode choice. The MIT Office of the Provost has attached employees' ages to the data for all invited employees in the 2010 and 2012 surveys. Date of hire data is available for approximately 97% to 98% of all employees for survey years 2008 to 2014.

Table 3-12 and 3-13 summarize descriptive statistics for the age and time spent working at MIT, respectively, of all MIT employees.

Table 3-12: Descriptive statistics for employee age in years for 2010 and 2012

Survey Year	Mean	25th Percentile	Median	75th Percentile
2010	43.7	33	43	54
2012	44.6	33	42	55

Table 3-13: Descriptive statistics for years worked at MIT for 2008 to 2014

Survey Year	Mean	25th Percentile	Median	75th Percentile
2008	8.63	1.42	4.63	11.83
2010	9.41	1.83	5.33	13.67
2012	9.28	1.42	5.17	13.33
2014	8.92	1.33	4.42	13.25

Tables 3-12 and 3-13 suggest that values of employees' ages and time spent working at MIT are relatively consistent across years. The hire date data indicates that over a quarter of employees have less than two full-years of work experience at MIT. This population is of particular interest because new hires likely represent the youngest employees at MIT. Studying these new employees across years may provide some indication of whether or not shifting demographics in the MIT employee population have a significant impact on the mode choices for the Institute. This section evaluates the relationship between age and time spent working at MIT and mode choice to answer this question.

Using the data for 2010 and 2012, employees' ages and years of work experience at MIT are found to be strongly correlated (corr = 0.690). Figure 3-10 shows the relationship between years of MIT work experience and age for MIT employees and plots the best-fit line.

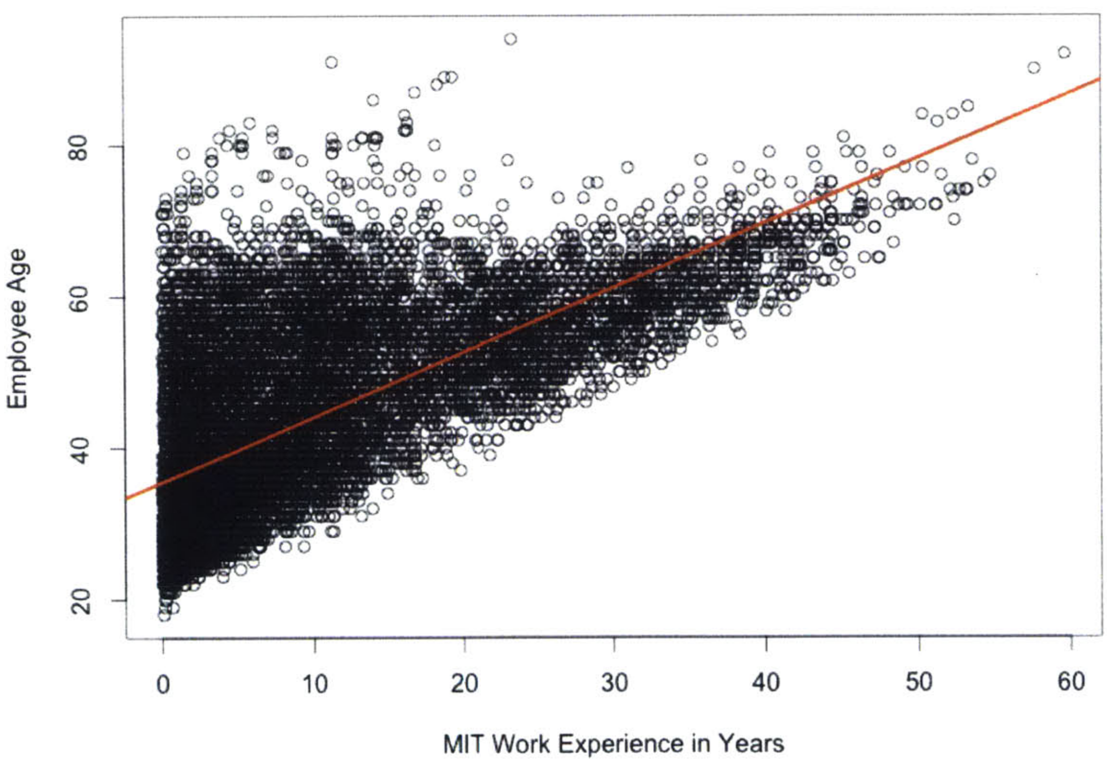


Figure 3-10: Relationship between MIT work experience and employee age for data from 2010 and 2012

Figure 3-10 suggests the intuitive positive relationship between MIT work experience and age. In Figure 3-10 there exists a rough set of natural boundaries that create a wedge shaped pattern in the points representing MIT employees. The flat boundary at the top of the plot corresponds to normal retirement age while the upward sloping boundary along the bottom of the plot corresponds to the set of employees who began working at MIT very early in their professional lives, likely soon after completing their schooling.

Next, this section examines the relationship between these variables and mode choice. Given that data on employee ages is only available for 2010 and 2012, MIT work experience data is used to model this relationship. Figure 3-11 shows the relationship between years of work experience and the value of the parking ratio for all years.

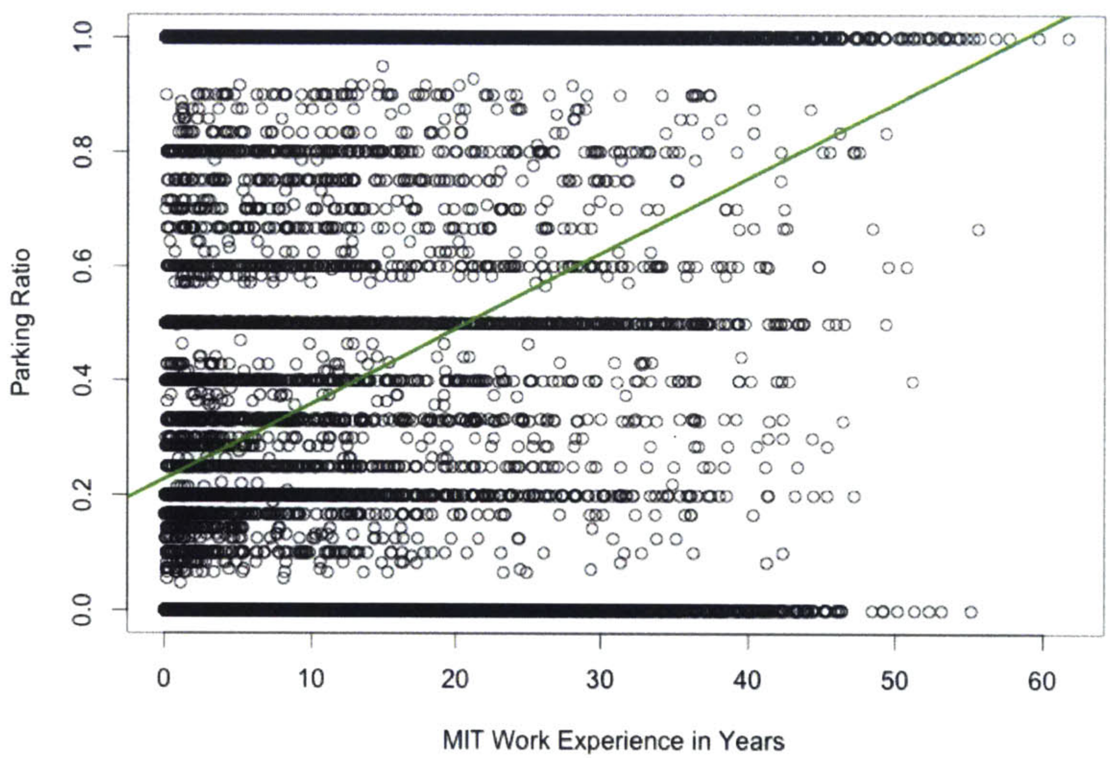


Figure 3-11: Relationship between MIT work experience and parking ratio for survey years 2008 to 2014

Figure 3-11 shows a pretty weak, but positive relationship between the two variables. Table 3-17 provides the results of a regression analysis for years 2008, 2014 and all years for which MIT work experience data is available for employees.

Table 3-14: Parking ratio related to years of MIT work experience

	2008	2014	All years^
(Intercept)	0.244***	0.216	0.229***
	(0.008)	(0.007)	(0.004)
Years of MIT work exp.	0.013***	0.014***	0.013***
	(0.001)	(0.001)	(0.000)
R-squared	0.086	0.108	0.099
Adjusted R-squared	0.086	0.108	0.099
No. observations	4,561	5,422	19,341

^ 2008 to 2014
Standard errors are reported in parentheses
*, **, *** indicate significance at the 90%, 95% and 99% levels, respectively

Table 3-14 suggests a weak positive relationship between MIT work experience and the value of the parking ratio. The coefficients suggest that an additional 15 years of MIT work experience predicts an approximate 0.2 increase in the value of the parking ratio, which corresponds to one additional SOV commuting day in each five-day workweek. The single variable model has R-squared values of approximately 0.1, indicating that it fails to explain approximately 90% of the variation in the data, and that its predictive value is very low.

Next, this section compares mode choice for new MIT employees and all survey respondents. As discussed in the introductory chapter of this thesis, some administrators believe that changing employee demographics, perhaps more than MIT's transportation benefits pricing, have been the primary drivers in reducing SOV mode share among MIT employees in recent years. To investigate this suggestion, only those employees who have been hired in the last two years at the time of each commuting survey are analyzed. Table 3-15 shows the estimated percentage of all employees that were hired in the last two years at the time of the survey in years 2008 to 2014.

Table 3-15: New employees for survey years 2008 to 2014

Survey year	Employees	% new employees (< 2 yr. tenure)
2008	11,111	30
2010	10,473	26
2012	10,775	30
2014	11,380	31

Table 3-15 shows that, across years, new employees account for about 26% to 31% of all employees. The percentage of new employees in the employee population is relatively consistent from 2008 to 2014, with the exception of 2010. The 2010 survey data points to a slower rate of hiring on the part of MIT between 2008 and 2010, and, in fact, the employee population decreased by about 650 during this time. Over the study period, 2008 to 2010 represents the only time period during which MIT's employee population did not increase. The timing of these effects suggests that the economic downturn was at least in part a driver of these effects. Figure 3-12, below, shows the calculated difference between the percentage of new employees and all employees using each mode.

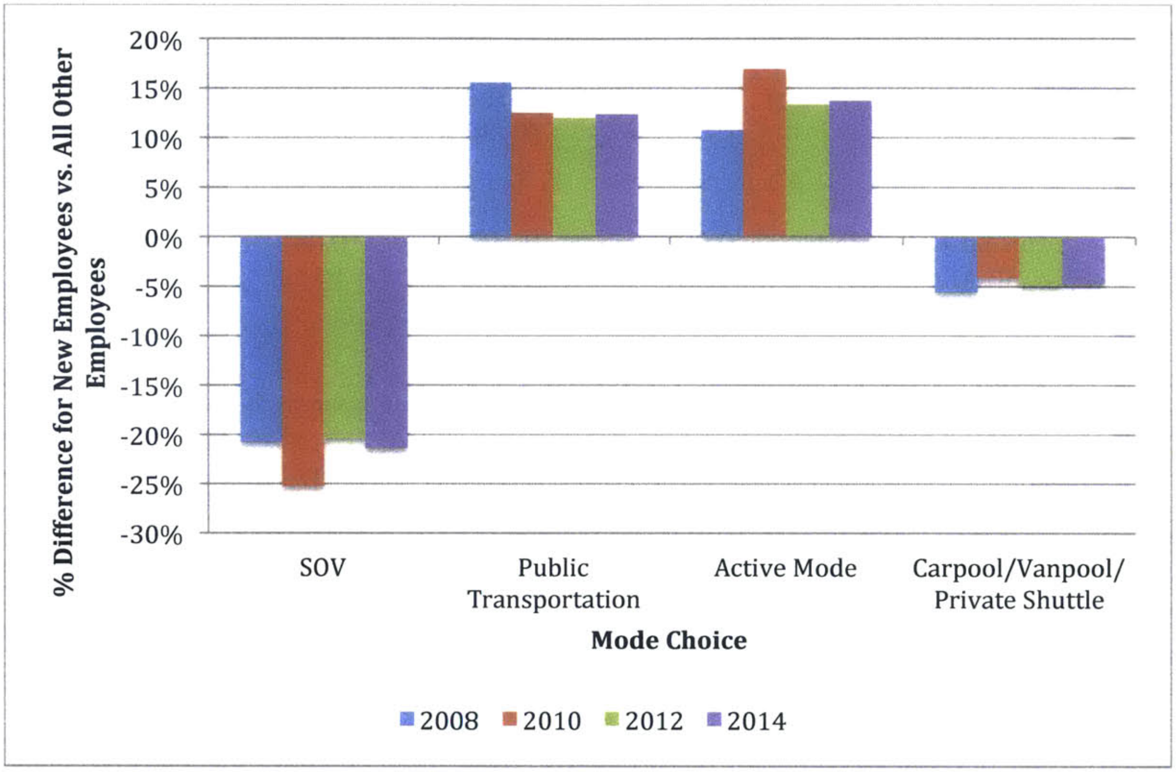


Figure 3-12: Mode choice differences between new employees and all other employees for 2008 to 2014

Figure 3-12 shows that a greater percentage of new employees commute by public transit and active modes compared to all other employees. From 2008 to 2014, the percentage of new employees using transit and active travel ranges from about 25% to 30% greater than that for all other employees. The opposite effect is observed for SOV and carpool/vanpool/private shuttle mode share. SOV mode share for new employees is between 20% and 21% lower for new employees than the rest of the MIT employee population, with the exception of 2010 where a 25% difference is observed. This may be due to the lingering effects of the economic downturn. New employees are likely to have among the lowest salaries, on average, so they were most likely more sensitive to the costs of owning, operating and parking a car. From 2008 to 2010, the percentage of new employees commuting by SOV decreased by 5.3% compared to a 0.8% decrease for all other employees. Omitting the special circumstances of 2010, the SOV mode share among new employees stays consistent relative to the mode share of all other MIT employees for all other years. Studying the value of the parking ratio for new employees and all other employees reveals a similar trend. Table 3-16 shows the average value of the parking ratio for new employees and all other employees for 2008 to 2014.

Table 3-16: Average parking ratio value by new hire status for 2008 to 2014

Survey year	New employees	All other employees	All employees
2008	0.19	0.43	0.35
2010	0.14	0.42	0.34
2012	0.19	0.43	0.36
2014	0.18	0.41	0.34

From 2008 to 2014, there has been a one-point increase in the percentage of new employees, as was shown in Table 3-15. Over this same time period, there has been an observed 1.5% decrease in SOV mode share for new hires compared to a 0.9% decrease in mode share for all other employees. Table 3-16 shows that the values of the parking ratios for new employees and all other employees follow a similar pattern. This suggests that the demographics of new hires may be one of a number of factors driving the observed changes in SOV mode share of the broader MIT employee community from 2008 to 2014. Across the years for which data are available, new hires are found to live closer to campus and transit services, on average, than all other employees. New employees are also generally characterized by lower rates of car ownership. These demographic characteristics are relatively consistent for new employees across years and likely explain much of the difference in the parking ratio values between new employees and all other employees.

New employees, however, tend to leave MIT in much greater percentages than do all other employees. For example, about half of 2008 employees with less than two-years work experience at MIT left by 2010, compared to about 20% of all other employees. By 2014, only 25% of employees designated as new hires in 2008 were still working at MIT, compared to 60% of all other employees. These attrition rates are found to be consistent for 2008 to 2014. This suggests that the attrition rate among new employees is much higher than that of the rest of the Institute's employee population.

The data presented in this section suggest that new employees drive to campus significantly less frequently than all other MIT employees. Demographic differences between new employees and other employees likely explains much of why new employees are less likely to use SOV and more likely to travel by transit and active modes than their counterparts. The analysis in this section, however, shows that the average driving frequency of the MIT employee population has stayed about constant from 2008 to 2014, suggesting that new employee demographics have not had a major impact on parking demand at the Institute over this period. While new employees may live closer to MIT and drive less, on average, the attrition rate among new employees is much higher than for all other employees.

The availability of date of hire data only for years 2008 to 2014 represents a limitation in investigating the effect of new employee demographics on employee mode choice at MIT. As Sections 3.2.1 and 3.2.2 demonstrate, almost all of the observed change in behavior between 2004 and 2014 is observed between 2004 and 2008. To infer the role employee demographics may have played in driving changes in employee mode share from 2004 to 2008, this analysis must look to the analysis of other variables presented in this chapter (which in some cases are similarly limited). If the conclusions of this section's analysis of new employee demographics for 2008 to 2014 are representative of 2004 to 2008, that would suggest that other factors must explain most of the decrease in SOV mode share. These factors may include the effects of transportation benefits pricing and personal preferences.

3.6 Employee Type and Salary

The MIT commuting survey groups employees into a number of categories: administrative staff, faculty, other academic staff, medical staff, research staff, service staff and support staff. These groups are also used to estimate employee salaries using data from the Integrated Postsecondary Education Data System. The IPEDS is a resource maintained by the National Center for Education Statistics (NCES) featuring aggregate data collected from individual universities on information such as enrollment and financials. To estimate employee salaries, this thesis uses aggregate MIT employee salary data available for public access on the IPEDS, which the NCES obtains through mandatory annual surveys of the Institute. Ranges in salary by employee type can be quite large, meaning that the explanatory power of these aggregated data will be limited in the context of this analysis.

Employee type and salary are investigated in this section because employee type may be a proxy for other important factors in mode choice determination such as work schedule and salary. Office and administrative staff, for example, are likely to work at MIT during regular business hours on weekdays, while some service staff may regularly work different hours and weekends. These characteristics are likely to play a role in employee mode choice. For example, public transportation services may not be operating everywhere at especially early or late times of the day, pushing workers with irregular hours toward SOV commuting. In the case of weekends, the Institute offers free access to parking to employees with a valid MIT parking permit, which may provide an incentive for weekend workers to drive to campus. In addition to likely capturing many of these factors, employee type is also likely strongly correlated with salary. Personal income may determine the probability of an individual owning a personal car for commuting and their sensitivity to costs such as the cost of gas, parking charges and transit fares. Employee type and salary is known for virtually all MIT employees. Table 3-17, below, shows statistics describing the MIT employee population by type in percentage terms for 2004 to 2014.

Table 3-17: MIT employee population by staff type for 2004 to 2014

Employee Type	2004	2014	Difference
Administrative	19.4%	20.2%	0.8%
Faculty	10.2%	9.1%	-0.9%
Medical	1.2%	0.9%	-0.3%
Other academic	31.1%	36.2%	5.1%
Research	12.6%	13.1%	0.5%
Service	9.1%	7.2%	-1.9%
Support	16.5%	13.4%	-3.1%

Compared to the distribution of employees described above, the survey data overrepresents administrative staff, research staff and support staff. Other academic staff and service staff are significantly underrepresented in the respondent data. Faculty and medical staff are represented roughly proportionally to their actual population numbers.

Next, salary is estimated by category for all years using data from the IPEDS on faculty and staff compensations for the study period. Average salary records are available on the IPEDS for MIT faculty and other academic staff for 2004 through 2014, but data for other staff is only available for 2012 to 2014. This thesis assumes 3% annual growth in staff compensation for years for which data is unavailable. The MIT Office of Provost identified 3% as a reasonably accurate and representative estimate of salary increases at MIT over the past decade. Table 3-18 summarizes the estimated average annual salary (before taxes) for employees by staff type and by year. All numbers are expressed in US dollars.

Table 3-18: Average annual salary in USD for MIT employees by staff type and year

Employee Type	2004	2006	2008	2010	2012	2014
Administrative	69,300	73,500	78,000	82,700	87,800	95,600
Faculty	112,000	121,800	138,600	143,300	156,900	169,900
Medical	57,300	60,800	64,500	68,400	72,600	77,300
Other academic	67,600	69,300	76,000	79,600	83,700	87,000
Research	67,400	71,500	75,800	80,400	85,300	88,400
Service	45,000	47,700	50,600	53,700	57,000	59,900
Support	42,700	45,300	48,000	51,000	54,100	58,300

From 2004 to 2014, faculty and other academic staff salaries have increased by an average of about 4% and 2.5% annually, respectively. For all other staff types, the data is not as complete, but these employees' salaries are assumed to have increased by approximately 3% annually, on average. Over this same period, the cost of an annual parking permit has increased by about 10% annually. Figure 3-13 shows the relationship between salary and mode choice for all years.

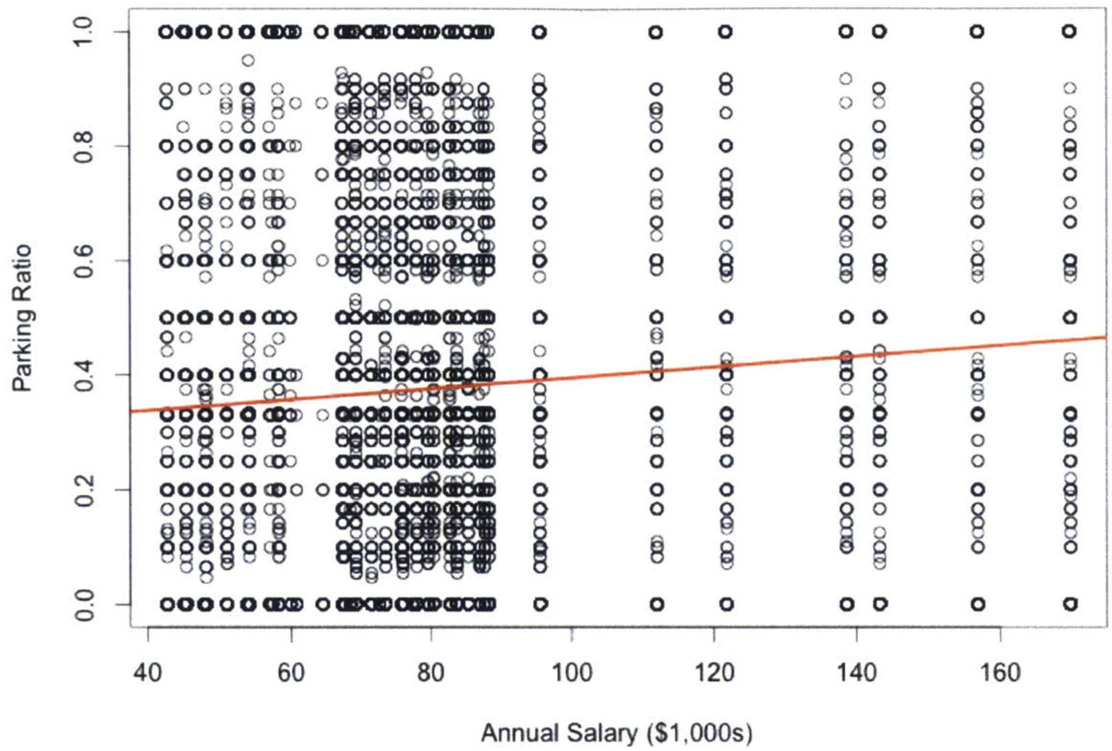


Figure 3-13: Relationship between salary and parking ratio for 2004 to 2014

Figure 3-13 shows a slight positive relationship between salary and the value of the parking ratio. Table 3-19 shows the results of a regression relating the parking ratio and salary for 2004, 2014 and all years.

Table 3-19: Parking ratio related to cost of parking as a percentage of employee salary

	2004	2014	All years^
(Intercept)	0.381***	0.185***	0.301***
	(0.028)	(0.020)	(0.009)
Salary ($1,000s)	0.001***	0.002***	0.001***
	(0.055)	(0.000)	(0.000)
R-squared	0.003	0.011	0.003
Adjusted R-squared	0.003	0.011	0.003
No. observations	3,352	5,441	27,163

^ 2004 to 2014
Standard errors are reported in parentheses
*, **, *** indicate significance at the 90%, 95% and 99% levels, respectively

Table 3-19 specifies the intercept and coefficients for the linear models for 2004, 2014 and all years. The R-squared values suggest that the model fails to explain virtually all of the total variation in the data. This suggests that the variable of employee salary alone cannot reliably predict mode choice. From 2004 to 2014, the median employee salary increased from about $68,800 to $88,400. The average value of the parking ratio for employees earning less than the median salary in 2004 was 0.405, compared to 0.254 in 2014. For employees earning salaries greater than the median, the parking ratio decreased from 0.528 to 0.403 over the study period. This suggests that MIT's transportation demand management strategies are having almost the same impact on both higher and lower salaried employees.

This section shows an increasing trend in employee salaries from 2004 to 2014. Over the study period, employees' annual compensation grows by an average of approximately 3% annually. The linear model presented suggests a positive relationship between salary and the frequency with which employees choose to park on campus, but this relationship is not robust. An analysis of the bottom and top 50% of earners shows similar decreases in the average values of the parking ratio from 2004 to 2014, suggesting that fewer employees are commuting by SOV now than a little more than ten-years ago despite the fact that wages have stayed ahead of inflation. This evidence further suggests that the observed trend of increasing salaries in not predictive of changes in mode share. It should be noted, however, that employee income likely plays a role in a number of factors that may be shown to be more strongly related to mode choice. Employee income is likely strongly correlated with the choice of where to live and whether or not to own a personal car, which have significantly greater influence on the employee's commuting method, as shown in Sections 3.3 and 3.4, respectively.

3.7 Transportation Benefits Subscription

The Institute offers employees an array of transportation benefit offerings, most notably subsidized parking permits and transit passes, which employees can purchase through the MIT Parking and Transportation Office. The next sections investigate trends in employees' purchase of parking permits and transit passes, respectively, over the studied time period.

3.7.1 Parking

The MIT Parking and Transportation Office maintains records of historical parking permit purchases. The Institute offers a number of parking permit types, which can be broken into three categories: annual permits, occasional permits and carpool permits. Annual permits provide employees unlimited access to campus commuter parking for the calendar year for a fixed annual fee. The occasional permits give employees access to parking for a small annual fee plus a daily fee charged each day they park. Carpool permits allow for designated MIT employee carpools to park on campus for one annual fee split among its members. The Institute offers additional parking permits to employees such as residential parking for faculty housemasters, but these represent a very small percentage of parking sales. Figure 3-14 shows the percentage of employees with annual, occasional or carpool parking permits for each year.

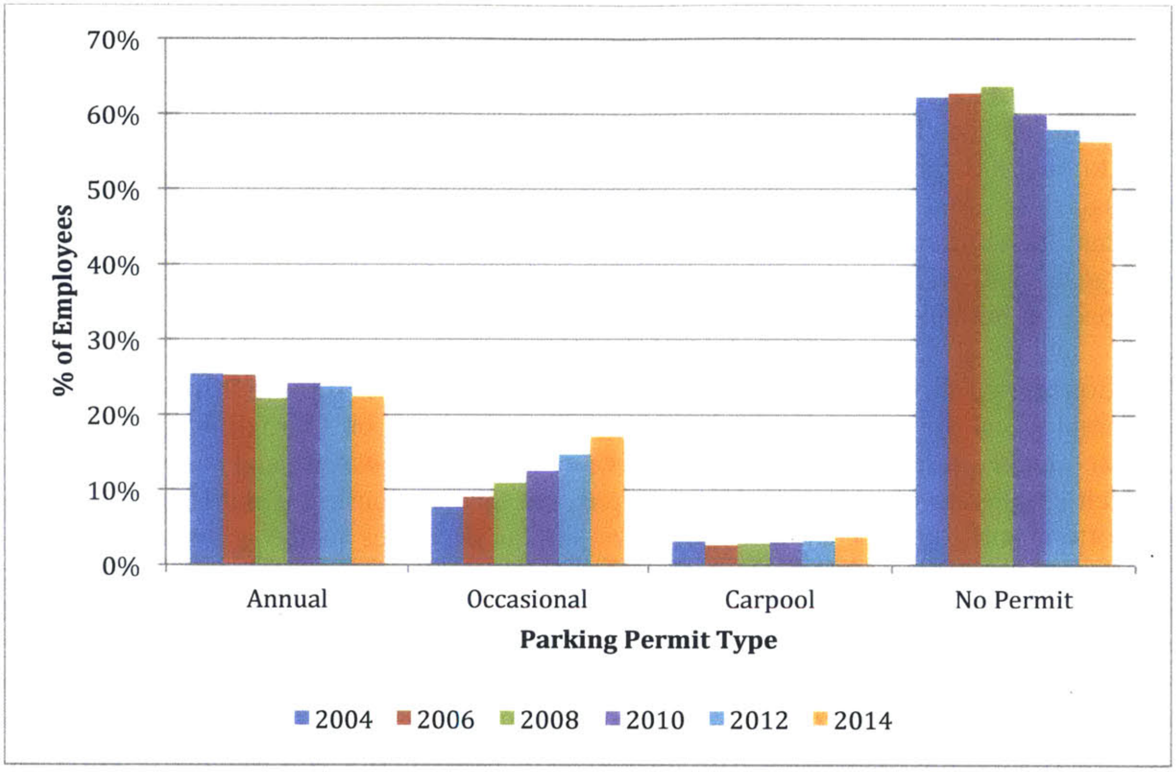


Figure 3-14: Percent of MIT employees by parking permit subscription for 2004 to 2014

Figure 3-14 shows a notable upward trend in the percentage of MIT employees purchasing an occasional parking pass. From 2004 to 2014, there is an approximately 10% increase in employees buying an occasional parking pass. Across years, about a quarter of the employee population is shown to buy annual permits and between 53% and 60% choose not to purchase parking permits. The increasing popularity of occasional parking permits may be driven by a number of factors. Unlike with the annual permits, buying an occasional permit allows employees to remain eligible to receive MIT's 50% subsidy for transit passes. In addition, the much smaller annual fee associated with the occasional permit makes it an attractive option for those employees who must drive occasionally (for example, due to family commitments such as dropping off a child at school) but have the flexibility to choose more sustainable and inexpensive modes other days. Table 3-20 demonstrates the relationship between employees' parking permit purchases and the parking ratio. Average values are shown for annual and occasional parkers.

Table 3-20: Average parking ratio value by parking permit status for 2004 to 2014

Survey year	Annual	Occasional
2004	0.91	0.25
2006	0.91	0.28
2008	0.89	0.25
2010	0.90	0.27
2012	0.90	0.29
2014	0.90	0.31

Table 3-20 shows different patterns in the parking ratio values for annual and occasional parkers from 2004 to 2014. Over the study period, values of the parking ratio stay relatively consistent for annual parkers suggesting that the commuting behavior of employees with annual permits has largely remained unchanged. Occasional parkers are characterized by generally increasing values, suggesting that, on average, employees with occasional permits parked on campus more often in 2014 than in 2004.

The analysis in this section demonstrates overall decreases in the percentage of employees purchasing annual parking permits and those purchasing no parking permits and steady increases in the percentage of employees buying occasional permits from 2004 to 2014. Despite some variation across years in average values of the parking ratio for occasional parkers and employees without parking permits, there is evidence of a strong relationship between parking permit subscription and mode choice. Self-selection likely represents the primary driver of the observed relationships between parking permit subscription and the parking ratio. Employees with personal preferences for certain modes choose a parking permit to accommodate those preferences. Despite the expectation that employees self-select the parking permit that best fits their commuting preferences, studies in behavioral economics suggest that the pricing characteristics of the annual versus the occasional permits can still significantly influence employees' behavior. Annual parkers pay for parking through a fixed annual fee, and therefore perceive the marginal cost of parking on campus to be zero. In contrast, occasional parkers likely more fully internalize the monetary and social costs of driving to MIT because they have to pay a daily rate to park. This may influence occasional parkers to be more conscious of their decisions of their method of commute and its implications.

3.7.2 Transit

In addition to parking purchase records, the MIT Office of Parking and Transportation also keeps data on the purchase and issue of subsidized MBTA monthly passes. Figure 3-15 illustrates trends in the purchase of MBTA LinkPasses and local bus passes and commuter rail/express bus/water shuttle passes by MIT employees across years.

Figure 3-15 shows a strong pattern of a growing percentage of employees purchasing MBTA transit passes through MIT. From 2004 to 2014, there is a 20-point increase in the percentage of employees buying a LinkPass or local bus pass and an approximately 4.5% increase in employees purchasing MBTA commuter rail, express bus or water shuttle passes. Over the same period, the percentage of employees purchasing no public transportation pass has decreased by nearly 25%, from 81% in 2004 to 57% in 2014. MIT currently subsidized all transit passes at 50%. The Institute first introduced a transit subsidy in 1996, contributing $10 per month. From 1996 to 2008, the subsidy gradually increased to its current level of 50% for all pass types. Many of the individuals buying no MBTA pass were ineligible for MIT's subsidy on transit passes because they purchase an annual parking permit. The previous section shows that the percentage of employees with annual parking was about 28% in 2004 and 26% in 2014. This suggests that about 25% of employees eligible for the Institute's public transportation subsidy bought a transit pass in 2004. By 2014, nearly 60% of individuals eligible for the transit subsidy bought a transit pass through MIT. This suggests very notable growth in the percentage of MIT employees purchasing transit passes over the study period. In 2008, when the transit subsidy increased to its current levels for all MBTA services including commuter rail, there is a relatively significant increase in the percentage of employees purchasing MBTA passes through the Institute. In 2008, the percentage of employees purchasing a LinkPass or local bus pass increases to 1.23 times that of 2006. Similarly, the percentage of employees with commuter rail, express bus or water shuttle passes is 1.32 times higher in 2008 than 2006. This suggests very positive employee response to the increased transit subsidy level. This significant growth in the percentage of employees purchasing transit pass has continued since 2008, as the percentage of employees holding transit passes of all types has more than doubled from 2008 to 2014. Table 3-21 illustrates the relationship between transit pass type and the parking ratio, showing the average value of the parking ratio for employees with and without transit passes.

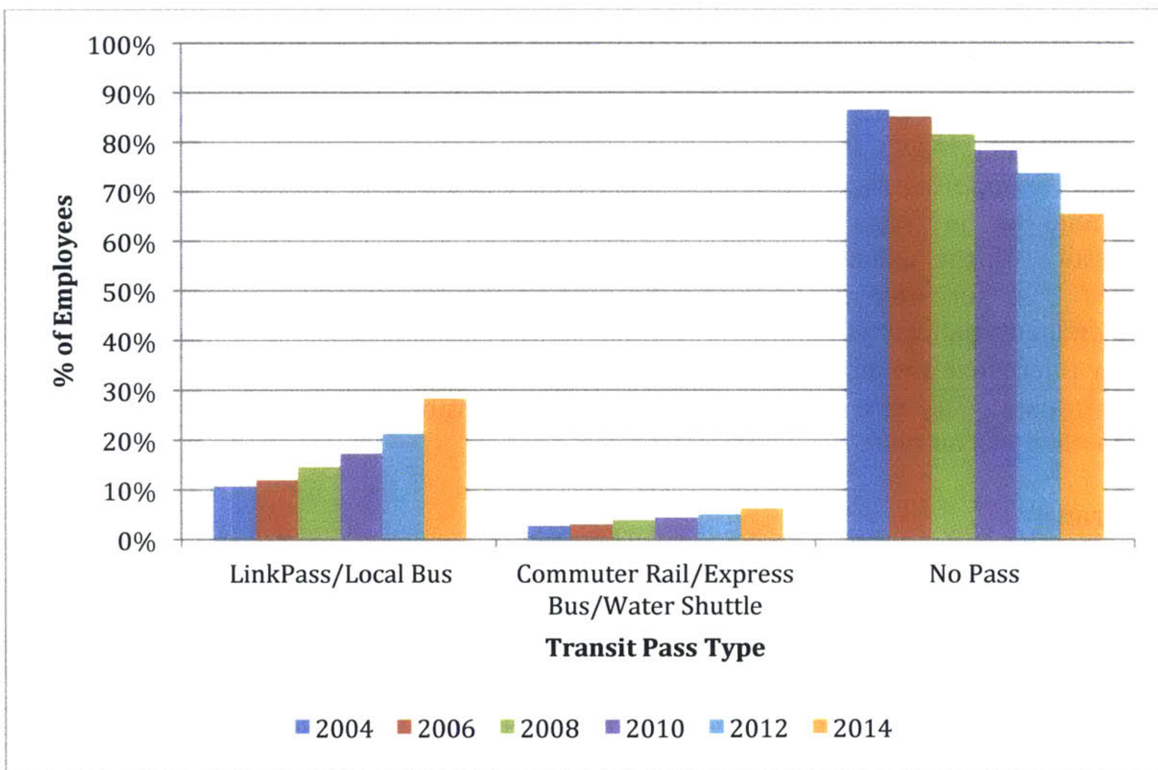


Figure 3-15: Percent of MIT employees by MBTA transit pass subscription for 2004 to 2014

Table 3-21: Parking ratio by transit pass type and year for 2004 to 2014

Survey year	LinkPass/Local Bus	Commuter Rail/Express Bus/Water Shuttle	No pass
2004	0.09	0.06	0.55
2006	0.08	0.07	0.52
2008	0.08	0.08	0.44
2010	0.07	0.09	0.46
2012	0.08	0.09	0.51
2014	0.07	0.08	0.55

Table 3-21 shows a common pattern across years in the relationship between the average values of the parking ratio and transit passes. Employees who purchase a transit pass park on campus with significantly less frequency, on average, than do their counterparts who do not purchase transit passes. Those employees that do not purchase transit passes may commute by SOV, carpool, private shuttle services or active modes. The parking ratios shown here suggest that transit pass holders park on campus about once out of every ten or 15 commutes, on average, compared to around once every other commute for employees without a transit pass.

The analysis in this section points to significant growth in the percentage of employees purchasing transit passes through MIT, especially since 2008 when the Institute increased the transit subsidy level to 50% for all MBTA passes, including commuter rail. Furthermore, this section demonstrates that transit pass holders, on average, are characterized by much lower parking ratio values, suggesting they demand parking much less frequently than their counterparts without transit passes. As with parking permits, self-selection again likely represents a significant driver in the relationship between transit pass status and the parking ratio. Employees choosing to purchase transit do so because they live near transit and commuting by transit aligns with their personal preferences and budget. Many employees choosing not to buy transit passes through MIT likely do not live in areas where transit is readily accessible or may live so close to MIT that they prefer to commute by active travel. The trends observed in this section, however, suggest that the Institute's public transportation subsidy has been successful in attracting more transit users among its employee population, who in turn park less than those employees without transit. Again, as the percentage of employee transit riders has grown, so has the absolute number of MIT employees on campus, so the percentage increases in transit ridership may not necessarily translate to decreased parking demand on campus as measured by an absolute number of spaces. This is investigated in the next section of this chapter.

3.8 Estimating Parking Demand at MIT

The above sections have outlined trends in mode choice, employee demographics and transportation benefits selection for years 2004 to 2014. This section estimates parking demand at MIT using data on the real numbers of employees and parking spaces at MIT main campus over the course of the study period. Table 3-22 reports the number of employees and parking spaces at MIT for all survey years. The Institute reserves a number of parking spaces for student commuters, but makes virtually all other spaces available to employee commuters. The Institute issued parking permits to about 750 students in 2004 and fewer than 300 in 2014.

Table 3-22: Number of employees, all parking spaces and employee commuter spaces at MIT for 2004 to 2014, Sources: MIT Office of the Provost, MIT Parking and Transportation Office

Survey Year	Employees	Parking Spaces	Student Parkers	Employee Spaces
2004	9,504	4,753	750	4,000
2006	10,218	4,612	530	4,080
2008	11,111	4,562	470*	4,090
2010	10,473	4,371	420*	3,950
2012	10,775	4,174	360*	3,810
2014	11,380	4,237	300	3,940

*Interpolated estimates

The travel diary in the survey is used to estimate parking demand for each day, Monday through Sunday, for each survey year. The parking demand results from the survey sample are then multiplied to estimate the aggregate demand for parking spaces for all MIT employees working on main campus. Table 3-23 shows the estimated aggregate parking demand for survey years 2004 to 2014. Parking demand is shown to be highest Monday through Thursday, with slightly lower levels of demand on Friday and significantly lower estimates for weekends. Table 3-23 shows estimated levels of peak parking demand for a regular weekday (Monday through Thursday) based on reported commutes in the survey travel diary for each year. For context, the costs of annual parking and occasional parking are shown.

Table 3-23: Estimated aggregate parking demand for 2004 to 2014

Survey Year	Estimated aggregate parking demand (spaces/day)	Annual Parking Price	Occasional Parking Price
2004	3,900	$518	$30/yr + $4/day
2006	3,840	$638	$30/yr + $4/day
2008	3,280	$786	$44/yr + $4/day
2010	3,020	$968	$55/yr + $4/day
2012	3,080	$1,192	$67/yr + $5/day
2014	3,000	$1,455	$74/yr + $7/day

Table 3-23 shows a significant decrease in parking demanded as measured by an absolute number of spaces per day. From 2004 to 2014, there has been a decrease in parking demand by an estimated 900 spaces per day, representing an about 23% reduction in weekday parking demand. Over this same time period, MIT has added almost 1,900 employees, representing a 20% increase in the number of employees. The estimates of parking demand in this section suggest that MIT has been effective in its efforts to reduce the amount of parking it must provide despite a growing employee population. From 2004 to 2014, the Institute has already eliminated 500 parking spaces, and this analysis suggests that it can cut its parking stock even further. If MIT were to set a target of 85% parking utilization on an average weekday, for example, it could reduce its employee parking by an additional 500 spaces and still accommodate the estimated levels of demand for 2014.

This observed trend in decreasing parking demand has significant implications for MIT. In reducing parking demand, the Institute has been able to reduce its parking stock by over 500 spaces from 2004 to 2014, and can eliminate hundreds of additional spaces while still accommodating estimated current levels of demand. This can free up space for redevelopment that is much more valuable to MIT, such as the construction of additional classroom, office and laboratory space. In addition, the provision of parking spaces represents a significant net cost to MIT. In 2014, for example, MIT charged $1,455 for an annual permit and incurred a cost of approximately $3,500 per space per year for a net annual cost of $2,000 per space annually. In the years before 2014, MIT recovered an even smaller percentage of its parking costs due to lower parking prices. Assuming a cost to MIT of $3,500 annually to provide a parking space, the elimination of 500 spaces corresponds to a cost savings of over $1,000,000 annually. In the future, however, as space limitations require MIT to replace lost parking with underground spaces, the annual cost of providing parking will continue to increase. For its newest underground parking structures in Stata and Sloan, for example, MIT incurs a cost of approximately $6,000 per space per year. This means that a new 1,000 car underground garage entails an annual cost of $6 million per year. The entire cost of the current MIT transit subsidy is less than $2.4 million per year.

3.9 Summary

In the decade from 2004 to 2014, the survey data provides evidence that, overall, the percentage of employee commuters commuting by SOV has fallen by 12% and the percentage of employees commuting by primarily public transportation or active modes have increased by 8% and 5%, respectively. Analyzing demographic change over this same period, this chapter finds no clear evidence that significant changes in demographic factors can explain most or all of these changes. Over this same time period, the percentage of employees purchasing transit passes through the Institute has more than doubled and the estimated use of SOV commuting among transit pass holders has remained consistently low across years. This suggests that transportation benefit pricing at MIT is playing a role in affecting the observed changes in employee commuter mode choice from 2004 to 2014, and needs to be investigated further.

The trend analyses of survey data in this chapter points to little change across years for the demographic variables evaluated. In Section 3.3, which investigates trends describing employee home location, the descriptive statistics and maps presented do not provide strong evidence of significant trends in employees' choices of where to live. Across years, different methods are used to estimate the geographic location of employees' places of residence, which provides additional challenge in interpreting the determined statistics and distributions. A spatial analysis of employee mode choice for employees living at a variety of distances from MIT, however, suggests that MIT's transportation benefit pricing strategies are likely having a notable impact on all employees, regardless of whether they live especially close to campus or farther away. This spatial analysis also finds that are still many SOV commuters living in areas well served by transit. For example, in census blocks with transit mode share above the median (42%), still fully 13% of employees commuted by SOV in 2014. This suggests that there still are a significant number of MIT employees that will likely respond to improved incentives by taking transit instead of driving.

Evidence of some change is found for rates of automobile ownership among MIT employees. Section 3.4 demonstrates a gradual pattern of employees choosing to maintain lower rates of car ownership over the course of the study period, but it is difficult to conclude that this trend is a driver of decreasing rates of SOV commuting and an increasing percentage of employees using transit and active modes to get to and from work. This is because when individuals purchase cars, they generally do so already with well-defined expectations for how they plan to use the car and what commuting method best fits their budget and personal preferences. The decreasing rates of automobile ownership may even suggest that employees are responding positively to MIT's TDM measures and deciding that they may not need to replace a car, for example.

The evaluation of trends in other demographic descriptors also helped to identify the possible effects of other factors, such as general economic conditions. In evaluating trends in the rate of hire of new employees in Section 3.5, this chapter finds that new employees (those with less than two-years tenure at MIT) account for a significantly smaller percentage of the total work force in 2010 than in 2008, 2012 and 2014. This shows that the rate at which MIT hired new staff slowed between 2008 and 2010, years corresponding to the general economic downturn. Between the 2008 survey and 2010 survey, MIT's employee population decreased by approximately 650 employees. This time period represents the only period between 2004 and 2014 during which MIT's employee population did not increase. Studying the relationships between mode choice and new employees compared to all other employees yields evidence that the economic downturn may have also impacted employee mode choice in a significant way. In 2010, the percentage of employees commuting by SOV is shown to be smaller than in 2008 and 2012, especially for new hires, who are likely to have lower salaries, on average, than their counterparts. This suggests that the economic downturn and recovery may have played a role in employee mode choice, especially for lower salaried workers.

Section 3.6 demonstrates a trend of increasing average salary for MIT employees based on data collected by the National Center for Education Statistics and estimates of average annual growth in employee compensation from the MIT Office of the Provost. While the value of estimated employee salaries is shown to very clearly increase across years, this chapter shows models relating salary and mode choice to have negligible predictive power. This is likely due to factors such as increasing parking costs and inflation, and most likely, the fact that much of the influence of income on mode choice is better captured in models of related variables such as descriptors of home location and automobile ownership. From 2004 to 2014, significant decreases are observed in the average value of the parking ratio for employees belonging to both the bottom 50% and top 50% according to salary.

Section 3.7 shows significant trends in transportation benefits subscription among MIT employees. Most notably, there have been very steady increasing trends in the percentage of employees purchasing occasional parking permits and transit passes of all types. An analysis of average values of the parking ratio according to parking permit time suggests that annual parkers are driving equally frequently across years. From 2004 to 2014, occasional parkers are driving more often, though still significantly less than annual parkers. Employees purchasing transit passes are shown to drive to campus much less frequently, on average, than their counterparts who do not buy a transit pass through the Institute.

To conclude, the analyses discussed in this chapter find no clear evidence that trends in any key demographic factors have had a significant role in the observed changes in mode share and parking demand over the study period. Instead, some findings may suggest that MIT's nudging is truly affecting behavioral change among MIT employees. Some observations point to the possible short-term influence of external factors on mode choice as well, such as the general economic conditions in the area. Of those factors discussed in this chapter, however, there are especially notable trends in the purchase of parking permits and transit passes, as the cost of parking to the employee has increased by about 11% each year and MIT increased its transit subsidy to 50% for all pass types in 2008. This suggests that the effect of transportation benefits pricing changes, in particular, should be investigated further using a more comprehensive method of analysis. Chapter 4 seeks to better evaluate the effect of transportation benefits pricing changes on employee mode choice by analyzing the dynamics of transportation benefits selection across years.

4 Analyzing Transportation Benefits Selection and Parking Frequency

4.1 Introduction

Chapter 3 examined trends in employee mode choice and parking frequency (as measured by the parking ratio – a measure of a given employee's use of campus parking divided by the number of days they report a commute trip to MIT) for 2004 to 2014. The chapter also examines general trends in demographic descriptors measured in the MIT commuting survey and related data sets, including employee home location, levels of car ownership, work experience and salary. The analysis in Chapter 3 shows a general decreasing trend in the parking frequency of survey respondents from 2004 to 2014. This trend is then compared against trends in various demographic characteristics in order to determine if shifting demographics seems to be driving this behavioral change over time. Chapter 3 did not find strong evidence of significant trends over time in important factors such as employee home location. Among demographic variables with notable trends over time, no strong evidence was found of significant causal relationships between the demographic variable and the parking ratio. For example, car ownership among MIT employees has declined from 2004 to 2014, but this trend is likely the result of reciprocal causation. That is, MIT employees are choosing to maintain lower levels of car ownership because their behaviors are changing. Analysis in Chapter 3, however, did show that new employees live closer to MIT and closer to transit and commute by SOV less frequently than all other employees, on average, a finding that is explored further in this chapter. Finally, Chapter 3 describes trends in employee purchases of transportation benefits at MIT: parking permits and transit passes (sold to employees at a discount through the Institute).

This chapter builds on the analysis and findings discussed in Chapter 3, by examining trends in individual employees' transportation benefits selection, or "bundles," and measures related changes in parking frequency across years. Parking frequency is a measure of a how often the employee parks on MIT campus in single parking space equivalents. That is, if an employee carpools with one other employee, that counts as "half-time" parking as compared to when the employee drove to campus alone. To describe employees' transportation benefits purchases, this chapter defines a set of five bundles describing the parking permit and/or transit pass held by each individual employee for a given survey year. The bundles are: (1) an annual parking pass, (2) an occasional parking pass and no transit pass subscription, (3) an occasional parking pass plus a transit pass, (4) a transit pass and no parking subscription, and (5) no parking or transit subscription.

Chapter 3 shows strong relationships between parking permits and transit passes and the parking ratio. This chapter combines parking and transit into bundles in order to examine the relationship between bundles and parking frequency, in greater detail. In addition, this chapter examines trends in bundle selection across years and investigates any differences that might exist among these trends for different segments of the MIT employee population. The analysis in this chapter, for example, seeks to evaluate the differences between new employees, MIT's most established employees and all other employees in terms of transportation benefits bundle selection and behavior across years. As it investigates these trends, this chapter also discusses the demographic characteristics, pricing factors and exogenous factors that may be most relevant to the observed changes in bundle selection and behavior across years. This chapter begins with a review of the pricing of transportation benefits at MIT from 2004 to 2014. Next, the chapter examines trends in bundle selection and parking frequency across years for a number of defined samples of the MIT employee population. Lastly, this chapter concludes with a discussion of the likely drivers of any observed trends as well as the implications of any findings.

4.2 Transportation Benefits Pricing at MIT for 2004 to 2014

This section provides an overview of the prices charged to employees from 2004 to 2014 for MIT's most popular parking offerings, the annual and occasional parking permits, and for monthly MBTA passes purchased through MIT. From 2004 to 2014, MIT has changed the pricing of parking each year. For transit, the MBTA changed fares three times in the ten-year study period and MIT made some changes to the amount of subsidy it offers to employee transit riders. This section presents a comprehensive table showing the prices charged to MIT employees for these parking permits and a range of transit passes across years and provides a brief description of these changes.

Table 4-1 provides an overview of the prices charged to the employee for the annual and occasional parking permits and MBTA monthly passes. The prices shown in the table do not reflect the actual full cost to MIT of providing these benefits. The costs to employees for MBTA monthly passes are expressed in dollars per month. The percentages in parenthesis represent the portion of the market cost for a given transit pass that are subsidized by MIT. Table 4-1 also includes a calculation of the ratio of the cost of an annual parking permit and the cost of annual LinkPass subscription for employees across years.

Since 2004, MIT has increased the cost of an annual parking permit by approximately 11% annually. Employees purchasing annual permits pay one annual charge prorated on monthly basis and incur no direct costs for parking at MIT other than this charge. Despite increasing the cost of annual parking 11% annually, the Institute still heavily subsidizes the cost of parking for annual parkers. In 2014, for example, while employees with annual permits were charged a total annual fee of $1,455, MIT incurred an estimated cost of about $3,500 per space per year to provide parking. For its newer underground parking, MIT incurs a cost of at least $6,000 per space per year. This represents roughly a 60% to 75% subsidy. Annual parkers are not eligible for MIT's subsidized transit pass offerings.

There are two types of charges for occasional parking permits at MIT. Employees purchasing occasional permits pay a small annual charge and incur a daily charge for each day they actually park on campus. Increases in occasional parking charges at the Institute have not been as consistent as have charges for the annual parking permit from 2004 to 2014. In addition to the access to subsidized parking, employees purchasing occasional passes are still eligible to take advantage of MIT's subsidized public transportation offerings.

Table 4-1: Transportation benefit offerings cost to the employee for years 2004 to 2014

		2004	2006	2008	2010	2012	2014
Annual Parking	Annual Fee:	$518	$638	$786	$968	$1,192	$1,455
Occasional Parking	Annual Fee:	$30	$30	$44	$55	$67	$74
	Daily Rate:	$4	$4	$4	$4	$5	$7
MBTA Monthly Passes	Local Bus	$12 (61%)	$15.5 (61%)	$20 (50%)	$20 (50%)	$24 (50%)	$25 (50%)
	LinkPass	$35.5 (50%)*	$29.5 (50%)	$29.5 (50%)	$29.5 (50%)	$35 (50%)	$37.5 (50%)
	Zone 1A		$29.5 (50%)	$29.5 (50%)	$29.5 (50%)	$35 (50%)	$37.5 (50%)
	Zone 1	$53 (50%)	$67.5 (50%)	$67.5 (50%)	$67.5 (50%)	$86.5 (50%)	$91 (50%)
	Zone 2	$59 (50%)	$79 (48%)	$75.5 (50%)	$75.5 (50%)	$94.5 (50%)	$99 (50%)
	Zone 3	$69 (46%)	$91 (44%)	$81.5 (50%)	$81.5 (50%)	$106 (50%)	$111 (50%)
	Zone 4	$90 (40%)	$114 (39%)	$93 (50%)	$93 (50%)	$114 (50%)	$119.5 (50%)
	Zone 5	$111 (35%)	$138 (34%)	$105 (50%)	$105 (50%)	$126 (50%)	$132.5 (50%)
	Zone 6	$122 (33%)	$151 (32%)	$111.5 (50%)	$111.5 (50%)	$137.5 (50%)	$144.5 (50%)
	Zone 7	$132 (31%)	$163 (31%)	$117.5 (50%)	$117.5 (50%)	$145.5 (50%)	$153 (50%)
	Zone 8	$139 (30%)	$178 (29%)	$125 (50%)	$125 (50%)	$157 (50%)	$165 (50%)
	Zone 9	$139 (30%)				$164.5 (50%)	$172.5 (50%)
	Zone 10					$172.5 (50%)	$181 (50%)
	Inner Express Bus		$44.75 (50%)	$44.75 (50%)	$44.75 (50%)	$55 (50%)	$57.5 (50%)
	Outer Express Bus		$64.5 (50%)	$64.5 (50%)	$64.5 (50%)	$80 (50%)	$84 (50%)
	Commuter Boat	$139 (30%)	$139 (50%)	$99 (50%)	$99 (50%)	$131 (50%)	$137.5 (50%)
Annual Parking Cost / LinkPass Cost		1.22	1.80	2.22	2.73	2.84	3.23

*Designates the cost to the employee for a "Combo" pass in 2004 (the LinkPass was introduced as a result of the MBTA's 2006 fare reorganization and changes)

Employee charges for transit passes represent the most nuanced among those shown in Table 4-1 because of the number of products and the fact that the prices employees pay depend on both MIT and the MBTA. The MBTA changed the price of its monthly pass products three times over the ten-year period examined in this thesis: in the summers of 2006, 2012 and 2014. The change in 2006 involved some reorganization in the pass types (resulting in the introduction the LinkPass, which provided lower cost transfers), but otherwise these changes have represented simple fare increases. The Institute began subsidizing transit passes for employees in 1996, and, in 2008, these subsidies reached current 50% levels (in percentage terms). Prior to 2008, MIT offered a flat contribution for most transit passes, which represented a subsidy at less than the 50% level for most commuter rail passes. In 2008, the Institute announced that all transit passes would be subsidized by 50% for employees. Additionally, to promote the use of transit in 2008, MIT offered a free monthly transit pass to annual parkers for that September. All employees, except those purchasing annual parking permits, are eligible to purchase subsidized transit passes through MIT.

As the cost of new parking at MIT has risen to $6,000 per space per year, MIT has increased the price of parking and has continued to contribute more toward employees' purchase of transit passes. The relationship between the cost of parking and transit to employees has changed dramatically. Table 4-1 shows a calculation of the ratio of the cost to the employee of an annual parking permit divided by the cost to the employee of an annual LinkPass subscription as an example to explain this trend. In 2004, the cost to employees of annual parking was about 1.2 times that of an annual LinkPass subscription for the employee. By 2014, this ratio increased nearly threefold, to a value of 3.2.

4.3 Analysis of Bundle Selection and Behavior

4.3.1 All Employees

Using records of parking and transit purchases from the MIT Parking and Transportation Office, each employee's bundle is determined for each survey year. Table 4-2 shows the percentage of employees choosing each transportation bundle for 2004 to 2014.

Table 4-2: Percentage of MIT employees by bundle for 2004 to 2014

Survey Year	Annual Parking	Occ. Parking (No Transit)	Occ. Parking w/ Transit	Transit Only	None of the Above
2004	31.6%	7.8%	4.1%	8.7%	47.8%
2006	31.2%	9.1%	4.5%	10.0%	45.2%
2008	26.2%	9.4%	5.8%	12.1%	46.5%
2010	26.8%	9.0%	6.6%	14.6%	42.9%
2012	25.8%	10.1%	7.2%	18.5%	38.4%
2014	23.3%	10.3%	8.1%	26.0%	32.4%

Table 4-2 shows significant trends in the bundle selection of all MIT employees across years. The percentage of employees buying annual parking permits decreases across years. The share of employees choosing the annual parking bundle decreases most significantly between 2006 and

2008 (by five percentage points). Between 2012 and 2014, there is another significant drop in the percentage of employees buying annual parking permits, a 2.5-point decrease. The percentage of employees choosing the occasional parking, occasional parking with transit and transit only bundles are characterized by strong upward trends. The percentages of employees choosing the occasional parking with transit bundle approximately doubles over the study period. The share of employees choosing the transit only bundle almost triples from 2004 to 2014. Across years, there exists a decreasing trend in the percentage of employees electing to buy neither parking permits nor transit passes through MIT.

Next, the survey response data is used to calculate averages in the parking ratio for each bundle across years. Table 4-3, below, shows the estimated average parking frequency for the five bundles for each survey year.

Table 4-3: Average parking frequency by bundle for 2004 to 2014

Survey Year	Annual Parking	Occ. Parking (No Transit)	Occ. Parking w/ Transit	Transit Only	None of the Above
2004	92%	31%	14%	2%	12%
2006	92%	36%	15%	3%	8%
2008	90%	30%	17%	2%	8%
2010	91%	36%	17%	2%	5%
2012	91%	38%	19%	3%	6%
2014	91%	45%	19%	2%	9%

Sample sizes: $n_{04} = 3{,}451$, $n_{06} = 4{,}698$, $n_{08} = 5{,}007$, $n_{10} = 4{,}857$, $n_{12} = 5{,}330$, $n_{14} = 5{,}947$

Table 4-3 shows strong relationships between bundle selection and behavior across years. Annual parkers drive to campus and park most frequently and their behavior remains consistent across years. Employees with occasional parking and no transit pass park about a third as frequently as annual parkers in 2004, but half as frequently as annual parkers by 2014. Occasional parkers with transit passes park less frequently, on average. Employees with only transit passes are shown to have parking ratio averages of near zero across years. Employees in the "none of the above" bundle are shown to drive to campus very infrequently as well.

To estimate the total average parking frequency of MIT employees across years, the reported parking frequency averages are weighted by the percentage of employees choosing each bundle across years. Table 4-4 presents the estimated average values of the parking ratio for all MIT employees across years. Note that these numbers are different than the average parking ratio values reported for survey respondents in Chapter 3, because the survey data over represents some bundles while underrepresenting others.

Table 4-4: Estimated average parking frequency for all employees for 2004 to 2014

Survey year	Mean
2004	38%
2006	37%
2008	31%
2010	31%
2012	31%
2014	31%

Table 4-4 shows a decrease in the average value of the parking ratio for MIT employees between 2004 and 2014. Almost all the observed change in this metric, however, occurs between 2006 and 2008. Reviewing Table 4-2, shown earlier in this section, that the percentage of employees choosing the annual parking bundle is shown to decrease by five percentage points between 2006 and 2008. In this same time, the percentage of employees with transit passes increases relatively significantly. The percentage of employees with occasional parking permits and transit passes increases more than a percentage point from 4.5% to 5.8% from 2006 to 2008, and the percentage of employees buying transit only increases from 10% to 12%. In addition, Table 4-3 shows a relatively significant drop in the average parking frequency for occasional parkers without transit between 2006 and 2008. The decrease from 36% in 2006 to 30% in 2008 represents an approximately 17% reduction in parking among all employees choosing the occasional parking without transit bundle, which accounted for nearly 10% of all MIT employees in 2008.

In Chapter 3, measures describing home location are found to be relatively consistent across years. Furthermore, evidence of changes in home location on an individual level is determined to be very infrequent. With respect to the other demographic variables explored in this thesis, the analysis in Chapter 3 concludes that that these variables are either (1) only very weakly correlated with behavior or (2) more likely characterized by reciprocal causation. For example, an employee's expectations of their own behavior and personal preferences likely determine whether or not they choose to buy a car rather than the other way around. Therefore, this analysis looks to pricing characteristics and exogenous factors to try to explain the change in the average value of the parking ratio between 2006 and 2008.

Table 4-1, presented earlier in this chapter, shows the prices charged to employees for annual and occasional parking permits and monthly transit passes. From 2006 to 2008, the cost of an annual parking permit increased by 23%. For an occasional parking permit, the annual fee increased from $30 to $44, while the daily charge remained the same, at $4 per day. The MBTA did not change charges for monthly passes between the 2006 surveys and 2008. However, in the summer of 2008, MIT announced that it would begin subsidizing all transit passes, including commuter rail passes for all zones, at a level of 50%. As a result of the increased subsidy, employees experienced a significant decrease in the cost of commuter rail monthly passes.

MIT announced the increase in the subsidy level for commuter rail passes in the summer of 2008 as part of a larger initiative targeted at encouraging full-time drivers to change their commuting behavior. The Institute offered all full-time drivers (employees that parked on campus five days a week) a transit pass for the month of September at zero charge to the employees. Approximately 700 MIT employees took advantage of this offer and signed up for the free transit passes. In addition to the increased transit subsidies and the offer of free transit for a month, MIT also sought to promote the occasional parking program to full-time drivers with annual parking permits. In 2008, the occasional parking program allowed employees to park only up to eight days per month for $4 per day. Annual parkers that switched to occasional parkers were then eligible to take advantage of MIT's new 50% subsidy on all MBTA passes (Sankar, 2008).

A couple of exogenous factors also likely contributed to the significant drop in the average value of the parking ratio for all MIT employees between 2006 and 2008. These factors include gasoline prices and general economic conditions. The summer and early fall of 2008 were characterized by a spike in the real price of gasoline – that is, the price of gasoline normalized by the Consumer Price Index (US Energy Information Administration, 2016). In addition, economic conditions and outlook were declining during this same time. From summer 2007 to winter 2009, for example, the S&P 500 (often used an indicator of general economic conditions) dropped nearly 50%. These factors likely contributed to the decrease in SOV commuting and parking demand observed at the Institute between 2006 and 2008. Higher real gas prices and worsening economic conditions likely made employees more responsive to the financial incentives offered by the Institute. The timing of MIT's commuter benefits initiative likely played an important role in the major shifts in bundle selection and behavior observed between 2006 and 2008. The promotion of the initiative likely reminded employees of the breadth of transportation benefits options offered at MIT at a time when many employees may have been looking for ways to reduce their personal commuting expenses. The increased awareness of MIT's range of transportation benefits options may have challenged many employees to reconsider their bundle selection, a decision that the employee may not have otherwise really considered as a result of established routines or habits.

Looking at the most recent years in the study period, 2012 and 2014, no significant change in the average parking frequency is observed, however, there are interesting changes in bundle selection and the behavior by bundle. From 2012 to 2014, the percentage of employees purchasing annual parking decreases by 2.5%. In addition, the percentage of employees purchasing transit increases by 7.5 percentage points and the percentage opting for no transportation benefit bundle decreases by six percentage points between 2012 and 2014. The percentages of employees selecting the occasional parking and occasional parking with transit bundles increase by 0.2% and 0.9%, respectively. This may suggest that about half of the net decrease in annual parkers went to the occasional parking program and the remainder converted to full-time transit use, while a significant number of "no benefit" employees also decided to purchase monthly transit passes.

Between 2012 and 2014, there is also one especially notable change in parking frequency between years for employees purchasing occasional parking permits only. From 2012 to 2014, the parking frequency of occasional parkers increases from 38% to 45%. This change in behavior is quite significant, corresponding to about a 20% increase in parking frequency for occasional parkers from 2012 to 2014. In any year, employees may reselect their same bundle or switch their benefit bundle. The percentage of employees switching from the occasional parking bundle to the annual parking bundle is less than 6% between 2012 and 2014, a minimum for the study period. Across years, some occasional parkers are found to switch to annual parking, but the number of employees making this switch between 2012 and 2014 is the lowest found over the study period. This suggests that a number of occasional parkers who may have otherwise switched to buying an annual parking pass may have decided to remain occasional parkers rather than buy an annual pass which increased from a cost of $1,192 to $1,455 from 2012 to 2014. These employees on the margin, deciding between the reselecting the occasional parking bundle or annual parking bundle likely drive more than all other occasional parkers. Thus, the decision of many of these individuals to remain occasional parkers may explain some of the increase in the parking frequency of occasional parkers in 2014. Though they represent a smaller share than in previous years, the employees switching from annual parking to occasional parking between 2012 and 2014 also contributed to this increased average. This increase in parking frequency, however, represents a less significant contribution to the overall average parking frequency of all employees in 2014 than if these employees had switched to annual parking.

In the period between the 2012 and 2014 surveys, real gasoline prices were relatively high and characterized by some uncertain volativity. There was an overall decrease in real gas prices between the 2012 and 2014 surveys. In addition, this period was characterized by improving economic conditions. Decreasing gas prices and improving economic conditions generally drive increases in SOV commuting. These factors may also explain some of the increase in the average parking frequency for employees with occasional parking between 2012 and 2014. Overall, however, there is no significant change in the average parking frequency of all employees from 2012 to 2014. This suggests that the increases in SOV behavior influenced by these exogenous factors were offset by transportation benefits pricing factors.

4.3.2 Panel Analysis

Next, this chapter examines a panel data set describing employees for whom transportation benefit bundle is known for all six survey years in the study period. From 2004 to 2014, there are about 2,700 employees for whom bundle is known in every survey year. Of these 2,700 employees, approximately 650 responded to all six surveys. The analysis detailed in this section studies these same 650 employees across years. Studying this panel data set provides the advantage of being able to evaluate trends in bundle selection and behavior for the same unique employees over time in isolation from the effects of employee turnover. Table 4-5 shows the percentage of 650 employees in the panel data set choosing each transportation bundle for 2004 to 2014.

Table 4-5: Percentage of panel employees (650) by bundle for 2004 to 2014

Survey Year	Annual Parking	Occ. Parking (No Transit)	Occ. Parking w/ Transit	Transit Only	None of the Above
2004	49.4%	5.8%	13.9%	25.7%	5.2%
2006	48.1%	6.6%	15.6%	24.9%	4.7%
2008	41.6%	9.9%	18.5%	24.0%	6.0%
2010	41.5%	8.7%	19.6%	24.9%	5.4%
2012	42.0%	8.8%	19.1%	24.4%	5.7%
2014	39.6%	9.9%	18.6%	24.3%	7.6%

Table 4-5 shows a significant decrease in the percentage of employees in the panel data set choosing the annual parking bundle across years. The percentage of employees choosing the transit only bundle also generally decreases over time, though the change is relatively small. The occasional parking, occasional parking with transit and none of the above bundles all show a generally increasing trend across years. Similar to the analysis of all employee data shown in Section 4.3.1, the most significant movement in bundle selection seems to occur between the 2006 and 2008 surveys. Between 2006 and 2008, the percentage of employees buying annual parking decreases by 6.5%, while the percentages of employees choosing the occasional parking and occasional parking with transit bundles both increase by approximately 3%. Another large decrease in the percentage of employees choosing the annual parking bundle occurs between 2012 and 2014. Although there are similarities between the trends in bundle selection for panel employees and the analysis of all employees (Table 4-2), a much greater percentage of the panel employees self-select into the annual parking and occasional parking with transit bundles, and there are far fewer who do not select any transportation benefit compared to the full MIT population for all years.

Next, Table 4-6 shows the calculated average parking frequency for the panel data set for the five bundles across years.

Table 4-6: Average parking frequency for panel employees by bundle for 2004 to 2014

Survey Year	Annual Parking	Occ. Parking (No Transit)	Occ. Parking w/ Transit	Transit Only	None of the Above
2004	91%	22%	12%	2%	9%
2006	89%	26%	14%	2%	12%
2008	88%	33%	17%	2%	13%
2010	89%	35%	13%	1%	5%
2012	89%	27%	19%	1%	5%
2014	90%	37%	15%	2%	10%

Table 4-6 shows significant differences in the average parking ratio by bundle. Annual parkers are shown to park most frequently, followed by employees with occasional parking and occasional parking with transit. Table 4-7, below, shows the overall average value of the parking ratio for the employees in the panel across years.

Table 4-7: Estimated average parking frequency for panel employees for 2004 to 2014

Survey year	Mean
2004	49%
2006	48%
2008	44%
2010	43%
2012	44%
2014	44%

Table 4-7 shows a downward trend in the average parking ratio for panel employees that is similar to that for all employees as was shown in Section 4.3.1. Rather than decreasing from 0.38 to 0.31 across years (as for all employees), the average parking frequency for panel employees only decreases from 49% to 44% from 2004 to 2014. Thus, panel employees park more frequently than their fellow employees, on average (see Table 4-4). In addition, the magnitudes of the observed changes in the average parking ratios for panel employees and all employees suggest that the parking frequency of employees described in the panel data set has not decreased quite as significantly as that of all employees. However, Table 4-7 still points to significant change in the commuting behavior of the 650 panel employees, again, between 2006 and 2008. The decrease in the average parking frequency from 48% to 44% corresponds to a roughly 8% decrease in parking demand among panel employees between 2006 and 2008.

The most significant change in the average parking ratio for panel employees occurs between the 2006 and 2008 surveys. This suggests that the drivers of this change are likely the same pricing factors and exogenous factors that were discussed in the analysis of bundle selection and parking frequency for all employees. These factors include increasing parking charges; a major MIT commuter benefits initiative involving increasing transit subsidies, an offer of a free one-month transit pass to full-time parkers and promotion of the Institute's occasional parking program; a spike in real gas prices; and a deterioration of general economic conditions. The decrease in the average parking ratio shown in Table 4-7 and the shifts in bundle selection shown in Table 4-5 suggest that a notable proportion of the employees represented in the panel data set responded to these incentives and factors.

Between 2006 and 2008, there is a 13% decrease in the share of employees choosing the annual parking bundle. About 10% of annual parkers in 2006 switched to occasional parking in 2008, accounting for most of this decrease. This provides strong evidence that MIT's 2008 initiative and promotion of the occasional parking program had a significant effect on employee bundle selection and, as a consequence, mode choice.

For 2012 to 2014, the parking frequency of the panel employees does not change significantly, but there are significant changes in bundle selection. There is an approximately 6% decrease in the share of employees selecting the annual parking bundle. The shares of employees choosing the occasional parking and none of the above bundles increase by 13% and 33%, respectively between 2012 and 2014.

As was observed for all employees, there is a significant increase in the parking frequency of occasional parkers between 2012 and 2014. This may be explained in part by a greater share of annual parkers switching to occasional parkers from 2012 to 2014 than in years prior. These employees likely switched to the occasional bundle in response to financial incentives, but drove more frequently than most other occasional parkers due to habits and preferences they developed as annual parkers. In addition, as was discussed in Section 4.3.1, the period between the 2012 and 2014 surveys was characterized by decreasing real gas prices and improving economic conditions. These factors also likely played a role in influencing the increase in parking frequency among panel employees selecting the occasional parking bundle. Despite decreasing gas prices and signs of economic growth, the average parking frequency of panel employees did not change between 2012 and 2014. Again, this suggests that the effect of exogenous factors that influence employees to drive more often were offset by the effects of employees' changes in bundle selection. Transportation benefits pricing characteristics are the most likely explanation of these observed changes in bundle selection, and the resulting changes in employee mode share.

4.3.3 New Employees

In Chapter 3, new employees (employees with less than two years of MIT work experience) are found to be less likely to purchase a parking permit and park on campus less frequently than their more established counterparts, on average. This section investigates trends in bundle selection and behavior among new employees across years. Data on the dates of hire for MIT employees were only available for years 2008 to 2014, and as such, new hires can only be precisely identified for survey years falling in this period. Given the finding of the prior analyses in this chapter that the most significant shifts in bundle selection and behavior occur between 2006 and 2008, however, a list of new employees as of 2006 is estimated by finding all MIT employees both invited to take the 2006 survey and not invited to take the 2004 survey. This approach should successfully capture data representing new employees in 2006, but it should be noted that hire dates for the employees in this created data set can only be verified for employees still employed by MIT in 2008. An analysis of only new employees across years provides a look into how MIT's newest employees behave compared to rest of the employee population. Given that new employees are defined as employees hired by MIT within the past two years, the sample of new employees in each survey year represents a collection of totally different individuals in each of the survey years. Table 4-8 shows the percentage of new employees choosing each transportation bundle for 2006 to 2014.

Table 4-8: Percentage of new employees by bundle for 2006 to 2014

Survey Year	Annual Parking	Occ. Parking (No Transit)	Occ. Parking w/ Transit	Transit Only	None of the Above
2006	18.1%	11.1%	3.7%	10.4%	56.8%
2008	14.3%	11.0%	4.4%	12.3%	58.0%
2010	10.2%	7.5%	4.1%	13.9%	64.3%
2012	14.8%	8.9%	5.8%	24.6%	45.9%
2014	11.9%	7.9%	7.4%	37.6%	35.2%

Table 4-8 shows generally decreasing trends in the percentage of new employees choosing the annual parking and occasional parking bundles. In contrast, the percentages of new employees choosing the occasional parking with transit and transit only bundles increase significantly across years. New employees in 2014 were twice as likely to purchase both an occasional parking permit and a transit pass than they were in 2006. Also, the percentage of new employees buying transit only in 2014 is more than triple the corresponding percentage in 2006. The percentage of new employees purchasing neither parking nor transit through MIT varies significantly, but represents a large share of new employees in all survey years. At a glance, the bundle selections of new employees are characterized by greater irregularity across years when compared to the percentages determined in the analyses of all employee data and the panel employees. This makes sense because there is no overlap in the individual employees represented across years.

To investigate trends in parking demand generated by new employees, Table 4-9 shows the average parking frequency for new employees by bundle across years.

Table 4-9: Average parking frequency for new employees by bundle for 2004 to 2014

Survey Year	Annual Parking	Occ. Parking (No Transit)	Occ. Parking w/ Transit	Transit Only	None of the Above
2006	92%	37%	15%	3%	6%
2008	91%	24%	18%	1%	5%
2010	92%	28%	21%	1%	3%
2012	92%	33%	19%	3%	3%
2014	92%	38%	19%	2%	5%

Sample sizes: n_{06} = 1,420, n_{08} = 1,550, n_{10} = 1,261, n_{12} = 1,639, n_{14} = 1,863

Table 4-9 demonstrates very consistent behavior among new employees with annual parking permits. The average parking frequency for new employees with occasional parking permits drops precipitously between 2006 and 2008, and then increases consistently from 2008 to 2014 back to its 2006 levels. The dramatic drop in the parking frequency of occasional parkers in 2008 may be attributable, at least in part, to high gas prices. The magnitude of this decrease is larger for new employees than for all employees or the panel employees. This may suggest that new employees (who are likely to have the lowest salaries, on average) are more cost sensitive than their counterparts. The average parking frequency for new employees selecting the transit and none of the above bundles stays at near zero levels across years. Table 4-10, below, shows the overall average parking frequency for new employees in survey years 2006 to 2014.

Table 4-10: Estimated average parking frequency for new employees for 2006 to 2014

Survey year	Mean
2006	25%
2008	19%
2010	14%
2012	20%
2014	18%

From 2006 to 2014, the average parking frequency for new employees ranges from a minimum of 14% in 2010 to a maximum of 25% in 2006. The averages provided in Table 4-10 show that, on average, new employees park significantly less than the average MIT employee. The lowest average parking frequency is observed in 2010. Unlike for all employees and the panel employees, there is a significant decrease in average parking frequency of new employees for not only 2006 to 2008, but also for 2008 to 2010. Between 2008 and 2010, the parking frequency of new employees decreases by five percentage points (compared to zero percentage points for all employees and one percentage point for panel employees). The demographic characteristics for new employees are investigated across years in order to determine if demographic differences between the groups of new employees might be causing this effect. Table 4-11 provides a summary of some of the most important demographic characteristics for new employees across years, the averages in the distance between home and MIT and the car ownership ratio for new employees.

Table 4-11: Average parking ratio, home distance and car ownership ratio for new employees for 2006 to 2014

Survey year	Avg. Parking Freq.	Avg. Home Distance	Avg. Car Ownership
2006	25%	5.9 miles	0.64
2008	19%	5.9 miles	0.61
2010	14%	n/a	0.54
2012	20%	6.9 miles	0.58
2014	18%	5.9 miles	0.58

Table 4-11 provides an overview of trends in home location and car ownership for new employees, two demographic variables shown to be most strongly related with the parking ratio in Chapter 3. Across years, new employees live an average of six miles from MIT, with the exception of 2012, when new employees are found to live approximately seven miles from MIT, on average. No home location data is available in the 2010 survey. The levels of car ownership seem to generally move with the value of the parking ratio across years. The lowest levels of car ownership among new employees are observed in 2010. This corresponds to the timing of the significant decrease in parking frequency between 2008 and 2010 that is observed for new employees, but not in the analysis of all employees or panel employees.

New employees in 2010 were hired by MIT between 2008 and 2010. The lower levels of car ownership among these employees may, in part, be a consequence of the higher gas prices and poor economic conditions that characterized especially 2008, at which time many of these new hires may have been making decisions concerning where to live and whether or not to buy a car. In addition, MIT's more active promotion of transportation benefits options in summer and fall of 2008 may have played a role in new employees in 2010 choosing to maintain relatively lower levels of car ownership. Summer and fall of 2008 may have been a time when many of these new hires were actively engaged in the hiring process or just beginning working at MIT. For many of these new employees, the financial incentives promoted by MIT in this 2008 initiative may have been a major factor considered in decisions concerning car ownership. The decrease in the level of average car ownership between 2008 and 2010 for new employees suggests that many of these employees chose to forgo buying a car because of the parking disincentives and transit incentives promoted by MIT and because they were especially sensitive to the costs of purchasing and owning a vehicle. This means that many new employees in 2010 may have more quickly adopted predominantly non-SOV modes than new employees in other years. This is a very interesting trend to watch. If it continues, it may indicate that the MIT transit incentives for employees may also reduce non-commuting vehicle miles traveled (VMT).

Looking at the most recent years in the study period, there is observed decrease in parking frequency for new employees between 2012 and 2014. Between these years, there is an observed shift away from parking bundles altogether for new employees. From 2012 to 2014, the share of new employees choosing annual parking decreases from 15% to 12%, and the share choosing occasional parking decreases from 9% to 8%. Meanwhile, there is significant growth in the share of employees buying occasional parking and transit or transit only. These shifts are likely related to an observed difference in the average home locations of new employees in 2012 and 2014. In 2014, new employees lived, on average, a mile closer to campus than new employees in 2012.

The parking frequency by bundle stays relatively consistent between 2012 and 2014, with the exception of a notable increase in the rate of parking among new employees with occasional parking permits. This is very similar to a pattern found in the analysis of all employees and panel employees, and is likely attributable to decreasing gas prices and improving economic conditions. Though gas prices and signs of economic growth may have encouraged increases in parking among new employees, it is likely that increased parking prices and a shift in the average distance new employees lived from MIT between 2012 and 2014 caused parking to actually decline among new employees for this time frame.

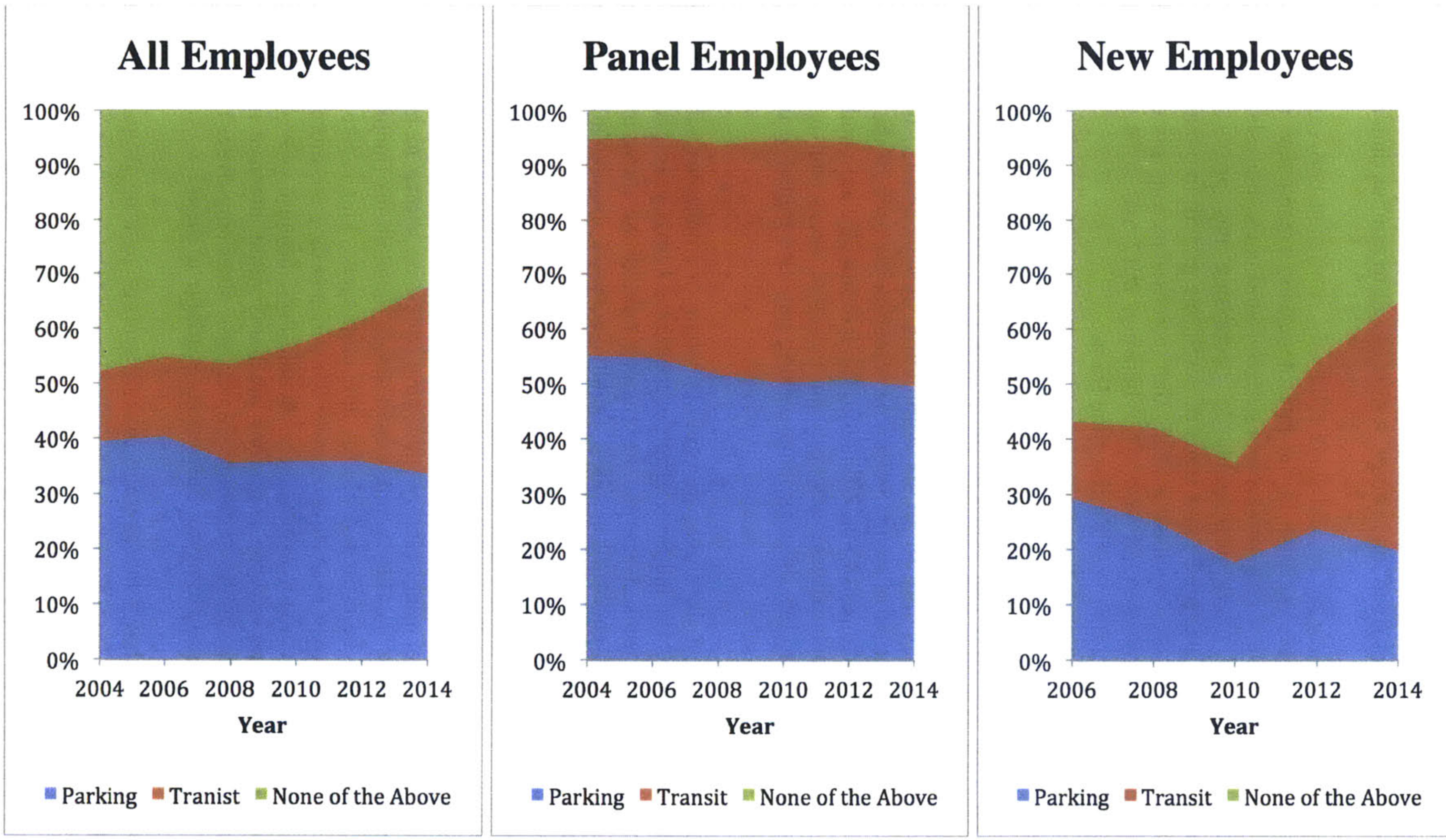
4.3.4 Comparing and Contrasting Bundle Selection and Behavior by Employee Sample

This seçtion compares and contrasts the dynamics of bundle selection and parking frequency over time for the three samples examined in this chapter: (1) all MIT employees, (2) a panel of 650 employees responding to all six commuting surveys and (3) new employees. Figure 4-1 provides a visualization of trends in bundle selection for each of the three samples explored in this chapter. For purposes of simplification, the five bundles are combined into three categories: (1) parking – those employees who buy an annual or occasional parking permit, (2) transit – those employees who buy an occasional parking pass and transit or transit only and (3) none of the above.

Figure 4-1 shows very different patterns in the share of employees with parking, transit and none of the above bundles for the three employee samples across years. For all employees, a smaller percentage of employees choose the parking and none of the above bundles over time, while the share of employees choosing a transit bundle increases dramatically. The percentages of all employees choosing parking bundles decrease most between 2006 and 2008 and 2012 and 2014. The panel data set represents the same exact individuals over the entire study period. For this employee sample, bundle selection is shown to be much more stable across years. The panel employees are generally much more likely to choose a parking or transit bundle than for the other employee samples. There is a slight decreasing trend in the share of employees choosing parking bundles over time. Finally, new employees are shown to have the smallest shares of employees choosing parking bundles over time. In addition, fluctuations in bundle selection across years tend to be most volatile for new employees. This is likely because new employees are likely paid less than their counterparts. This means they are more sensitive to price changes and change their behavior accordingly. In addition, because new employees are new to the Institute and often new to the area, they are likely more attentive in their decisions of which transportation benefit bundle to choose. In contrast, older employees may simply act out of habit and may not as carefully consider the options available to them.

Next, Figure 4-2 shows the average overall average parking frequencies across years for all employees.

Figure 4-1: Percent share of employees by bundle for all employees, panel employees and new employees for 2004 to 2014



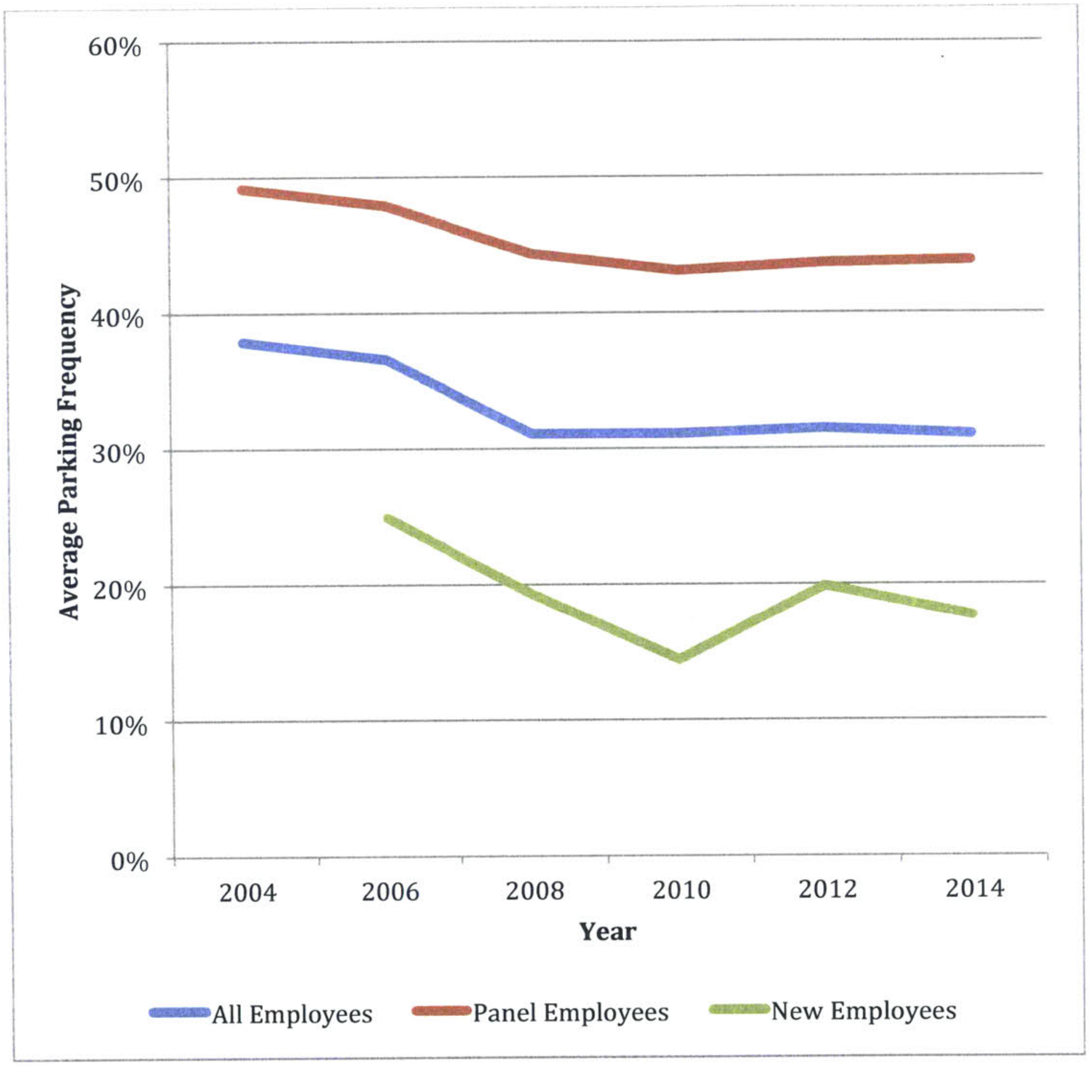


Figure 4-2: Estimated average parking ratio value for all employees, panel employees and new employees for 2004 to 2014

In Figure 4-2, the curves for all employees and panel employees are characterized by similar shape, while the curve for new employees exhibits greater vertical changes between 2008 and 2014. The more irregular shape of the curve for new employee likely corresponds to the increased sensitivity of new employees to exogenous factors such as gas prices and economic conditions, as was discussed in Section 4.3.3. Overall, this increased sensitivity makes new employees more responsive to transportation pricing incentives, on average, as evidenced by the differences between new employees and all employees in bundle selection (Figure 4-1) and behavior (Figure 4-2). Sections 4.3.1 through 4.3.3 (above) analyze and discuss likely explanations for the shapes of the curves.

4.4 Summary

This chapter provides an overview of pricing changes for parking permits and transit passes purchased through MIT across years. Over the study period, MIT has routinely increased the parking charges. In 2008, MIT increased its transit subsidy to 50% for all pass types as part of a initiative aimed at incentivizing full time parkers to drive to campus less frequently. The MBTA increased fares twice since 2008 (in 2012 and 2014), but MIT continues to subsidize transit at a level of 50%.

Next, this chapter presents analyses of three data sets: one describing all MIT employees, one describing the same 650 employees across all ten years of the study period and one describing new hires (employees hired by MIT within the last two years). The analyses seek to investigate trends in the employees' bundle selection and behavior over time. The analysis of all employees shows decreasing trends in the percentage of employees choosing the annual parking and none of the above bundles over time. The average parking ratio for all employees also decreases across years, but nearly all this observed change is shown to occur between the 2006 and 2008 surveys. The analysis of employees represented in the panel data set yields trends that are very similar to those found for all employees, although a greater percentage of panel employees select bundles with parking permits and they tend to drive to campus more frequently. For panel employees, most of the observed decrease in the parking ratio from 2004 to 2014 occurs between 2006 and 2008, as was observed for all employees. The timing of these decreases corresponds to the introduction of a major commuter benefits initiative at MIT involving increasing transit subsidies, an offer of a free one-month transit pass to full-time parkers and the promotion of the Institute's occasional parking program. In addition, the summer and early fall of 2008 were characterized by particularly high 'real' gasoline prices and deteriorating economic conditions.

An analysis of new employees shows that recent hires at MIT are less likely to select into parking bundles and drive to and park on campus significantly less than their counterparts, on average. The average value of the parking ratio for new employees follows a slightly different pattern across years when compared to the trajectories describing both all employees and the panel employees. Demographic differences between new employees and their counterparts may explain some of the differences in their behavior. On average, new employees live slightly closer to MIT and maintain lower levels of car ownership. An analysis of measures of these variables over time suggests that differences between the groups of new hires for survey years 2006 to 2014 may explain some of the variability between years in new employees' bundle selection and parking frequency. However, it may be more likely that the explanation that the new employee cohort has lower income and is therefore more sensitive to the economic incentives provided by the gradually increasing parking charges, which long term employees see as a modest change, but new employees perceive for the first time in relation to the increased transit benefit.

The analyses discussed in this chapter suggest that MIT's 2008 commuter benefits initiative was effective in incentivizing changes in behavior across the employee population. The initiative involved MIT's routine increases in parking charges, modest increases in subsidies for commuter rail passes, an offer of free transit for one month to full time drivers and the promotion of the Institute's occasional parking program. The timing of the initiative coincided with a spike in gas prices and continued deterioration of economic conditions. These factors may have heightened employees' responsiveness to the "nudges," or financial incentives, promoted by the new initiative.

Between 2012 to 2014, there is no evidence of changes in parking frequency, except for new employees (where parking frequency decreases), but there are still significant trends in transportation benefit bundle selection. For all employees, panel employees and new employees, there are observed decreases in the share of the respective samples that choose the annual parking bundle. This suggests that employees were responding to the approximately $260 increase in the annual parking charge between 2012 and 2014.

When investigating parking frequency, consistencies were observed for most bundles for 2012 and 2014, with the exception of occasional parkers. On average, the parking frequency of occasional parker increases significantly from 2012 to 2014 for all three employee groups analyzed. It is noted that this increase is likely related to decreasing real gasoline prices and improving economic conditions characterizing this time period and the shift of a significant number of annual permit parkers to the occasional parking permit. Despite the increased use of SOV commuting among some employees from 2012 to 2014, overall, the analysis in this chapter finds no increase in the total average parking frequency for MIT employees. New employees are even shown to exhibit a decrease in parking frequency from 2012 to 2014. These findings suggest that benefit pricing factors offset the effect of gas prices and economic conditions on overall parking frequency. This is evidenced by significant decreases in the share of employees selecting the annual parking bundle for this period.

5 Conclusions and Future Work

5.1 Summary

This research studied the evolution of transportation benefits pricing and commuting at the MIT Cambridge campus between 2004 and 2014. Using MIT's biennial commuting survey and related data sets, this research studies trends in employee demographic characteristics, transportation benefits pricing characteristics and other variables in order to explain the observed changes in employee commuting mode share from 2004 to 2014. This research finds correlations between mode choice and some employee demographic characteristics, but there are no dramatic changes in aggregate employee demographics over time. The research finds strong relationships between the evolution of transportation pricing at MIT and employee transportation benefit selection and behavior, suggesting that employees are responding to the transportation pricing incentives put in place by the Institute. The influence of these transportation pricing incentives are determined to be the most likely explanation for the observed changes in employee mode share. In the period of time studied in this thesis, MIT has steadily increased parking charges. Annual parking charges increased by 11% in each of the ten years between 2004 and 2014. Occasional parking charges have increased incrementally, approximately doubling over the ten-year period. In 2004 and 2006, MIT subsidized transit by 50% for MBTA monthly passes costing less than \$120 and provided a flat contribution of \$60 for all passes costing greater than \$120. In 2008, MIT announced it would begin subsidizing all transit passes at the 50% level, and has maintained this level since.

One of the primary motivations of this research is achieving a better understanding of the dynamics of commuting behavior at MIT in anticipation of the Institute's new commuter benefits program, *Access MIT*, which will be completely introduced in summer 2016. This program incorporates a range of incentives including, most notably: (1) an increase in all parking charges, to \$1,760 for annual permits and to \$10 per day for daily parking, (2) a shift to daily parking pricing for all gated parking lots and garages (representing over 85% of campus spaces), (3) an increase in transit subsidies to 100% for rides on MBTA local bus and subway services and 60% to 70% for commuter rail passes and (4) 50% reimbursement for parking costs at MBTA stations up to a maximum of \$100 per month. These incentives will make transit accessible to employees for zero marginal cost on the MBTA's local bus and subway network. The increased attractiveness of transit combined with higher parking costs and daily parking charges for all employees in gated lots will build on the demonstrated effectiveness of MIT's implemented transportation pricing incentives, or "nudges" to influence commuter behavior.

MIT has a major motivation to explore and implement these nudges because of the high (and increasing) costs it incurs in providing parking. With the introduction of its new commuter benefits program in the summer of 2016, MIT is taking another step to promote non-SOV modes and affect a reduction in employee parking demand in order to respond to these costs. As was described in Chapter 2, members of the Institute recognized the cost of providing parking as a significant long-term problem for MIT as early as the 1950s, but the first serious TDM measures were not put in place until the 1990s. In the 1990s, MIT introduced its first non-administrative parking charges and began subsidizing transit passes for employees. Since the 1990s, MIT has incrementally become more proactive with respect to exploring and implementing measures to reduce parking demand. As the Institute grows, however, parking costs are also increasing quite significantly. In order to allocate more land to classroom, laboratory and office space, MIT has been eliminating surface parking facilities and replacing that parking with underground garages. It costs the Institute at least an estimated $6,000 per year to provide each parking space in the underground garages in Stata and Sloan, which represent MIT's most recent parking construction projects. Recognizing these costs (and the even higher projected costs of future parking garages), it is in MIT's best interests to continue exploring and implementing TDM measures in order to effectively manage parking demand.

This research has shown that MIT's use of parking charges and transit subsidies has had a significant impact on employee mode choice. While growing parking charges result in increased revenue for the Institute, transit subsidies, which represent an expense to MIT, are shown to represent a cost-efficient measure for discouraging parking behavior. In 2014, MIT incurred a cost of about $2.4 million subsidizing the purchase of transit passes for 3,700 employees. In contrast, MIT incurred the same annual cost in 2014 to provide about 500 underground parking spaces. The worsening economics of parking provision should continue to motivate MIT to explore and enact effective incentives to reduce employee parking behavior well into the future. In addition, MIT's use of transportation pricing incentives serves an important role in minimizing the amount of campus land that must be allocated for parking facilities.

Chapters 3 and 4 present analyses and discussions of the MIT commuting surveys and related data sets in order to achieve a better understanding of the nature of the employee response to transportation pricing incentives at MIT. A few of the observed trends are highlighted here.

Over the study period, there has been a notable trend in decreased levels of car ownership among MIT employees. This trend in employee levels of car ownership is likely best explained by changing employee preferences and employees responding to incentives. As increasing parking charges and transit subsidies motivate MIT employees to commute to campus by modes other than SOV, new employees are choosing to not buy cars and established employees might choose not to replace a car. This has significant implications not only for the commuting behavior of these employees, but also for the mode choice of these employees for non-work related trips. Employees with lower levels of car ownership will be more likely to also use non-SOV modes for these non-work trips. This means that transportation pricing incentives at MIT may not only be effective in reducing work trip SOV mode share and vehicle miles traveled (VMT), but also affect reductions in VMT for non-work related journeys. As a result, the financial incentives offered by employers to target commuting behavior can have much broader positive implications not only for the employer, but surrounding communities as well.

Between 2006 and 2008, this research finds evidence of an especially pronounced decrease in average parking demand. Between the 2006 and 2008 surveys, parking demand decreased by an estimated 15% over the two-year period. While this period was characterized by high real gas prices and worsening economic conditions, a significant driver of this change in parking demand was judged to be MIT's 2008 commuter benefits initiative, which involved: (1) the regular 11% increase in annual parking rates, (2) an increase in the transit subsidy level to 50% for all passes, (3) an offer of one-month free transit for full-time drivers and (4) the marketing of MIT's occasional parking program to full-time drivers. The analysis of changes over this time period suggests that this initiative was very successful in affecting change among full-time drivers who may have otherwise not tried transit. About 700 full-time drivers signed up for the free transit pass and 15% of these employees canceled their annual parking permit subscriptions. Much of the change resulting from this program can be likely explained by the coordinated introduction of very attractive new pricing incentives and the effective promotion of those incentives. With the full introduction of the *Access MIT* program, the Institute has a unique opportunity to really impact how employees choose their commuting options on an ongoing basis.

5.2 Predicting the Impact of Access MIT

Studying historical data on transportation pricing, employee characteristics and employee mode choice for years 2004 to 2014 provides a context against which to estimate the possible effects of MIT's new commuter benefits program. Using simple measures of changes in the pricing of parking and transit at MIT and controlling for exogenous variables such as gasoline prices, some linear projections are used to estimate the anticipated impact of the *Access MIT* program on employee mode choice. A series of simple models is constructed relating average employee parking frequency to relative transportation benefits prices, gas prices and economic indicators across years. Based on the relative benefit pricing characteristics of years 2004 to 2014 and those proposed for the *Access MIT* program, these models suggest an estimated reduction in employee parking demand of between 10% and 15% from measured levels in 2014. This prediction represents a simple review of only the most macroscopic variables across years and does not capture the effects of a great number of factors including characteristics of individuals.

In addition to parking price increases and decreases in the cost of transit, which can be quantified, *Access MIT* also represents a number of significant changes that must be examined at a more qualitative level. The shift to daily parking pricing in all gated parking facilities, for example, represents a change in the way many employees will pay for parking. This change should have a significant impact on employee mode choice, especially because, as part of *Access MIT*, the Institute is expanding transit benefits by providing all employees with access to MBTA local bus and subway services at zero cost to the employee. In the time period studied in this thesis, MIT has offered a transportation bundle very similar in principle to this: occasional parking permit with transit. From 2004 to 2014, the share of employees choosing this bundle increased dramatically, mostly due to employees with annual parking or occasional parking only switching into this group. This played a role in achieving the observed decrease in parking demand reported in this research between 2004 and 2014. With the introduction of *Access MIT*, which bundles parking (at $10/day) with free transit for all employees parking in gated lots, two main factors are expected to contribute to reductions in employee parking demand: (1) the increase in the daily charge from $7 in 2014 and $8.50 in 2015, to $10 will contribute to a decrease in demand for parking and (2) *Access MIT* will represent a major change in incentives for employees who were previously annual parkers. For annual parkers, the cost of parking is a sunk cost, after which there is no marginal cost associated with parking on campus. In the Access MIT program, these parkers will now recognize each day parking on campus as a $10 expense and each day using another mode as a $10 (plus the auto operating costs) savings.

The combination of daily parking pricing and free universal transit will cause more employees to more clearly associate their commuting behaviors with dollar costs and savings. In addition, the structure also provides employees with greater flexibility. In write-in fields in the commuting surveys, many employees reported anecdotally that they drive to campus one or more days per week due to errands or an obligation such as dropping a spouse off at their workplace or a child off at school. Many of these individuals still regularly parked on campus on the other days of the week. With the new *Access MIT* program, these employees may switch to other modes on days when they do not have to complete any errands or to pick-up and drop-off a family member. The free transit pass bundled with daily parking will help reframe the way these employees may think about their commuting choices on days they would currently drive alone directly to and from work. Now these employees will perceive each day not parking as a $10 savings and they will have access to free transit, which they may have not felt inclined to purchase at an effective price of $37.50 per month.

Employee home locations represent another significant factor in considering the possible impact of the Access MIT program. Chapter 3 reports that, as of 2014, a significant percentage of regular parkers live in areas well served by transit. By providing free local transit access and putting in place $10 daily parking charges, these employees will likely reduce their parking behavior as they will now have free access to public transportation, which already represents a viable option for their commute. For employees living beyond areas served by local buses and the subway lines, *Access MIT* increases commuter rail subsidies and offers reimbursement for parking at MBTA stations. This represents a significant reduction of cost for use of commuter rail for employees and should increase interest in use of public transportation for additional employees living father away from campus.

5.3 Implications for Other Urban Employers

Many of the lessons learned in this thesis regarding the effectiveness of major TDM strategies, namely gradually increasing parking charges and transit pass subsidies, can also provide lessons for other urban employers. Chapter 3 demonstrates the demographic characteristics of the MIT employee population, and it is likely that these characteristics are very similar to those for the employee populations of many large urban employers. The findings presented in this thesis are likely most applicable to other employers in the Boston area. Some of the factors so integral to a complete review of TDM at MIT are related to its campus's location in an urban area with a developed transit network and high land values where parking is uneconomic. As such, the lessons learned in this thesis are likely most relatable to workplaces close to MIT.

The Boston area is home to a great number of employers, including private firms, hospitals and other universities. The TDM measures put in place at MIT may be applicable to any number of these. To determine how successful similar measures might be for another employer, it is important to evaluate the employer's situation and incentives. Urban universities like MIT, for example, generally own and operate their own parking but face severe constraints with respect to land availability. This provides these universities with short and long term incentives to manage parking demand and use the land available to them most efficiently, respectively. In contrast, many private-sector employers (such as the IT and biotechnology firms near MIT in Kendall Square) are tenants and do not own the parking they use. Property owners in Kendall Square traditionally bundle parking with office space in lease contracts. These parking arrangements of these contracts generally favors property owners by obligating tenant employers to pay for fixed amounts of parking that may be very different than the amount of parking the company would most prefer in terms of an efficient allocation of resources. In addition, these contracts often make it difficult or impossible for companies to sublet excess parking. In many situations, these factors can severely limit a firm's options and diminish its incentives for putting in place progressive TDM measures like the Institute's *Access MIT* program. Employers with more flexible leasing arrangements or with greater authority over their parking resources have more tangible incentives to reduce employee parking demand.

5.4 Future Research

The Access MIT commuter benefits program provides an extensive opportunity for future work building on this thesis. This research provides context on transportation pricing and commuting behavior at MIT for 2004 to 2014 to be compared to an evaluation of transportation pricing and commuting behavior following the introduction of *Access MIT*. An evaluation of the *Access MIT* program can determine changes in employee mode choice and measure the implications of the program on the annual cost to MIT in parking and transit subsidies.

The following recommendations should be considered regarding the data needed to support a rigorous evaluation of *Access MIT*.

To best identify changes in employee behavior influenced by MIT's new commuter benefits program, this research recommends collecting data on employees' commuting activity at time intervals significantly smaller than is done in MIT's current biennial commuting survey. Collecting data on employee mode choice and trip counts in the months or weeks before and after the introduction of *Access MIT* will enable researchers to more precisely measure changes in behavior that are a result of the incentives in the new program. By collecting data only once every two years, the commuting survey makes it much more difficult to isolate the effects of pricing stimuli than if many measurements are collected across a much smaller time frame. In a two-year period, it can be easy to miss factors that may influence an individual's commuting behaviors, such as an employee moving to a new home. While the MIT commuting survey data represents an informative tool for analysis of trends across a decade as was studied in this research, such infrequent measurements will be inadequate to understand the effects of *Access MIT* in the short-term or medium-term (a few weeks to a few months). Unlike the study in this research – a study across ten-years – a short-term evaluation can more reasonably minimize the role of changes in basic employee demographic characteristics over the study period, because the study period represents only a few weeks or months. As such it is likely sufficient to administer an initial survey of employees to identify relevant demographic characteristics. In order to facilitate increased frequency of data collection following an initial survey, it will be most practical to collect and analyze transaction data from employees' use of their parking and transit cards. This strategy would not require employees to fill out any more than the initial survey and will likely provide more accurate data than self-reported trip survey responses.

Even though they may not be dynamic variables in the context of a shorter-term study, consideration of demographic variables is still important. Demographic characteristics that can explain some of the nuances in behavior even in the short term will be particularly important. Visual inspection of write-in fields in the survey suggests that collection of additional variables could improve understanding of demographic and external factors that influence employee commuter behavior even in the short-term. For example, in the survey travel diary, many employees reported that their decision to drive to campus one or more days during the week was dictated by obligations such as dropping a child off at school or picking up their spouse at their workplace. Achieving an understanding of any other components in the trip purpose of employees' trips to and from work can help create a more complete understanding of a factor with significant influence on mode choice. External factors as simple as the weather may also represent a worthwhile factor to measure. Employees that may commonly walk or bike to campus, for example, may choose to drive or take transit in inclement weather.

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