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Rail-transit-induced gentrification and the affordability paradox of TOD

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ABSTRACT

Numerous studies have shown that rail transit has a positive effect on raising property values and tax revenues. Such an effect is widely viewed as an economic benefit for property owners and is key to justifying the high cost of building rail transit infrastructure. In recent years, however, concerns have been raised about rail transit acting as a gentrification trigger and causing the affordability paradox. In this study, I evaluate whether rail transit in suburban Portland caused neighborhood gentrification and reduced home affordability through a longitudinal quasi-experimental design. I use the propensity score matching method to identify control neighborhoods for rail-transit-served neighborhoods. I then make pretest-posttest comparisons between rail-transit-served neighborhoods and their control neighborhoods at multiple observation points. In general, I did not find consistent evidence for rail-transit-induced gentrification in suburban Portland. I did not find evidence that rail transit reduced home affordability for tenants and home owners in rail transit-served neighborhoods either. I observed more changes in the neighborhoods served by the Eastside line (the oldest rail transit line in Portland) than their control neighborhoods in the past three decades: socially, they attracted older and less-educated population; physically, they experienced densification and faster increases of the share of rental units in their housing stock. Rail transit was more likely to be installed along low-income neighborhoods in suburban Portland, confirming the necessity of constructing appropriate control neighborhoods while evaluating the neighborhood and social effects of rail transit.

1. Introduction

Transit-oriented development (TOD) has gained wide and ongoing popularity with the quick expansion of rail transit systems in American cities in the past few decades. Numerous studies have shown that TOD can promote economic development and increase nearby property values by improving transportation accessibility and offering more livable environment (Ahlfeldt and Wendland, 2009; Duncan, 2011; Gibbons and Machin, 2005). In the literature, TOD's positive effects on property values and tax revenues are widely viewed as an economic benefit and are key to justifying the high cost of building rail transit infrastructure (Smith and Gihring, 2006; Cervero and Duncan, 2002). In recent years, however, concerns have arisen about rail-transit-induced gentrification: a phenomenon whereby the provision of rail transit service and associated investment in station areas cause lower-status neighborhoods change to higher-status ones (Freeman et al., 2015; Kahn, 2007; Talen et al., 2015). One consequence of rail-transit-induced gentrification is the displacement of low-income households by middle- and high-income households and thus an affordability paradox of TOD (Renne et al., 2016), which in this study refers to a phenomenon that low-income households which would benefit from additional accessibility provided by upgraded transit are forced to move by rising rents and housing costs. Furthermore, because minority, low-income households tend to own fewer cars and use transit more often, the displacement effect of TOD may undermine its promise of increasing transit ridership (Pollack et al., 2010).

The social and neighborhood effects of public transit did not attract much attention in the literature until recently. A handful of existing studies have yielded mixed and often contradictory findings (Fan and Guthrie, 2012a, 2012b; Glaeser et al., 2008; Grube-Cavers and Patterson, 2015; Immergluck, 2009; Kahn, 2007; Pollack et al., 2010). At a time when many government agencies in the US have built or are building rail transit systems, developing a better understanding of the social and neighborhood effects of rail transit is critical to crafting more effective and equitable transportation and land use policies (Zuk et al., 2015).

In this study, I explore the social and neighborhood effects of rail transit in suburban Portland, Oregon through a longitudinal quasi-experimental design. I use the propensity score matching method to identify control neighborhoods for rail-transit-served neighborhoods and make pretest-posttest comparisons between the treatment and control groups at multiple observation points. The purpose is to examine whether rail transit caused gentrification and reduction of home affordability in nearby neighborhoods. In general, my analyses have not

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provided consistent evidence for rail transit acting as a gentrification trigger and causing the affordability paradox in rail-transit-served neighborhoods in the suburban Portland. I observed more significant changes in the neighborhoods that are served by the oldest rail transit line, suggesting that the social and neighborhood effects of rail transit take time to become apparent. The socioeconomic conditions in rail-transit-served neighborhoods were initially very different from typical neighborhoods in the region, confirming the necessity of constructing appropriate control neighborhoods when evaluating the social effects of rail transit.

The article opens with a brief review of related literature. The next section introduces my research design. The results of my analyses are then presented. In closing, I summarize and discuss the major findings of this study and suggest future research avenues.

2. Literature review

2.1. Defining and measuring gentrification

Studies of neighborhood change began with preoccupations about neighborhood decline and disinvestment. Traditional theories of neighborhood change, such as Burgess's (1925) invasion-succession model and Hoyt's (1939) filtering model, emphasize the downward movement of urban neighborhoods: higher-income residents begin to move out, usually to locations farther out from city centers, when neighborhoods age, deteriorate, and become obsolete (Wei and Knox, 2014; Skaburskis and Nelson, 2014). In the past few decades, research of neighborhood change has evolved into concerns about gentrification, a class-based phenomenon whereby low-income households are displaced by middle- and high-income households in combination with the reinvestment of the built environment (Clark, 2005, p. 258; Freeman et al., 2015; Skaburskis and Nelson, 2014; Zuk et al., 2015). Contemporary gentrification has become increasingly complex and may take a variety of forms (Davidson and Lees, 2005). Gentrification is no longer restricted to disinvested neighborhoods in inner cities. Recent studies have used the term of “gentrification” to describe upgrading in neighborhoods that have already experienced earlier rounds of gentrification and in neighborhoods that are in suburban and rural areas (Davidson and Lees, 2005; Landis, 2016).

Researchers have identified and measured gentrification in a variety of ways. Landis (2016) identifies four basic factors that can be used to measure neighborhood changes: 1) aggregate sociodemographic and economic characteristics of neighborhood residents and businesses; 2) physical, occupancy, and financial characteristics of the building stock; 3) specific number and characteristics of neighborhood newcomers; and 4) physical and capital investment flows into and out of neighborhoods. A large majority of prior studies have relied on the first two factors to measure gentrification because relevant Census data are readily available. Researchers tend to conclude that gentrification occurred when they observe a significant increase of residents of one or more of the following characteristics in a neighborhood: White, young, well-educated, middle- or high-income, living in small families, and in professional or management occupations (Atkinson, 2000; Landis, 2016; Freeman, 2005; Freeman et al., 2015; Hammel and Wyly, 1996; Hwang, 2016; Skaburskis, 2012; Skaburskis and Nelson, 2014; Walks and Maaranen, 2008). Prior studies usually describe the physical form of gentrification as the updating of aged buildings, increases of rents and home values, and tenure-switching from renting to owning (Hammel and Wyly, 1996; Immergluck, 2009; Kahn, 2007; Lin, 2002; Skaburskis and Nelson, 2014).

2.2. Rail-transit-induced gentrification and unaffordability

Transportation investment is inherently spatial and inevitably yields costs and benefits that vary across different neighborhoods (Farber et al., 2014; Golub and Martens, 2014). When a new rail transit line is built, changes are expected to occur in nearby neighborhoods as residents respond to the redistribution of transportation accessibility within the region. The impacts of rail transit on travel and land development are well documented (see Transit Cooperative Research Program [TCRP], 2004 and TCRP, 2008 for a detailed review). It is, however, far from clear whether rail transit causes gentrification and unaffordability in nearby neighborhoods. A limited number of existing studies have yielded mixed or even contradictory findings.

On the one hand, there is evidence that transit-served neighborhoods are more attractive to lower-income households who own fewer vehicles. Low-income households living close to rail transit stations can take the cost-saving benefit of transit by spending less on owning and using private cars (Dong and Hansz, 2016; Hamidi et al., 2016). The results of the National Household Travel Survey and many regional travel surveys consistently show that households with lower incomes and fewer vehicles are much more likely to use public transit than wealthier households (Giuliano, 2005; Olaru et al., 2011; Pucher and Renne, 2003; Thompson et al., 2012). Public transportation plays an important role in explaining why the poor live in American central cities: compared with automobiles that cost a lot to purchase and use, public transit offers a time-intensive alternative that is more appealing to those with low incomes (Glaeser et al., 2008). Therefore, rail transit may have the effects of attracting and retaining low-income households in nearby neighborhoods.

On the other hand, the provision of rail transit, especially in suburban areas, aims at recapturing middle-class, car-owning travelers as means of fulfilling broad social and environmental goals (Giuliano, 2005). It is argued that alternative neighborhoods that feature transit service and new urbanist design are undersupplied in U.S. metropolitan areas due to regulatory barriers (Levine et al., 2005; Levine and Frank, 2007). Transit-oriented neighborhoods are thus expected to attract the middle-class households who prefer to drive less and live in a compact, mixed-use neighborhood. Numerous studies show that better transit service leads to quicker housing appreciation in nearby neighborhoods (Ahlfeldt and Wendland, 2009; Duncan, 2011; Gibbons and Machin, 2005; Lin, 2002; Immergluck, 2009).

Empirical studies that directly examine whether rail transit causes gentrification and home unaffordability are very limited. Kahn (2007) uses a 14-city census tract–level panel data set to document the effects of rail transit expansions on communities nearby new stations. He finds that two of 14 cities (Boston and Washington D.C.) stood out in terms of gentrification effects of rail transit. He also finds that communities receiving increased access to new walk-and-ride stations experienced greater gentrification than communities that were close to new park-and-ride stations. Pollack and colleagues examine changes of income and housing cost in rail-transit-served neighborhoods in 12 metropolitan areas between 1990 and 2000, finding that both income and housing cost grew faster in rail-transit-served neighborhoods than they did in typical neighborhoods in the region (Pollack et al., 2010). A study in three large Canadian cities (Toronto, Vancouver, and Montreal) shows that proximity to rail transit had a significant gentrification effect in Toronto and Montreal, but not in Vancouver (Grube-Cavers and Patterson, 2015). Fan and Guthrie (2012a) quantify neighborhood changes in four rail and bus-rapid-transit corridors in the Twin Cities metro area. Their analyses find that younger workers increased faster in the four transit corridors than in the transit-served area as a whole, but the changes of the employment structure measured based on monthly wages were mixed. Fan and Guthrie (2012b) also explored residents' and businesses' perceptions of neighborhood social changes in the four transit corridors through questionnaire surveys. Their survey results show that both urban and suburban corridor residents expected positive neighborhood changes from new transit service, and urbanites tended to report slightly more positive perceptions.

In summary, the vast majority of gentrification literature has focused on individual and private actors and capital, and much fewer studies have addressed the role of public investment, and more

specifically rail transit investment (Zuk et al., 2015). Existing studies of the social and neighborhood effects of rail transit are very limited and yielded mixed or even contradictory findings. This study partially filled this research gap by evaluating whether TOD efforts in suburban Portland induced gentrification and home unaffordability in nearby neighborhoods. Furthermore, this study adopts a longitudinal quasi-experimental research design, which is more appropriate than cross-sectional analysis to discover the causal relationship between rail transit investment and neighborhood changes. Unlike previous studies that compare rail-transit-served neighborhoods with typical neighborhoods in a region, this study appropriately identifies control neighborhoods by a propensity score matching approach to ensuring an "apple-to-apple" comparison.

3. Research design

3.1. Longitudinal quasi-experimental design

I consider the inception of a new rail transit line a natural experiment and the group of neighborhoods that the new line serves a treatment group. Because gentrification is a dynamic process, it is necessary to compare the changes of neighborhood characteristics throughout time. I use a quasi-experimental design to make pretest-posttest comparisons between a group of transit-served neighborhoods and their control neighborhoods to determine whether the provision of rail transit service caused gentrification and home unaffordability in suburban Portland. The assumption is that if we can find almost "identical" neighborhoods in the control group for neighborhoods in the treatment group, the matching roughly assembles a true experiment with random assignment of rail transit service (Cao, 2010; Cao et al., 2010). As shown in Fig. 1, I have followed three steps to do the analyses. I first use the propensity score matching method to identify control neighborhoods for transit-served neighborhoods based on their pretest neighborhood characteristics. I then calculate the pretest-posttest changes of neighborhood characteristics of the treatment and control neighborhoods respectively. Lastly, I test whether the differences of the neighborhood changes between the treatment and control groups (also termed as "difference in difference" or "DID") are statistically significant.

3.2. Rail-transit-served neighborhoods in suburban Portland

This study focuses on suburban neighborhoods that are served by rail transit in the Portland, Oregon metropolitan area, a region with one of the most aggregative TOD programs in the United States (TCRP, 2004, p.355). The Portland region is now served by six light rail transit lines, one commuter rail line, and a street car system. The total length of the rail transit lines in the region is about 90 miles. The average weekday boarding rides of the entire fixed route transit system in the Portland region were 321,469 in fiscal year 2015 (Trimet, 2016).

Fig. 2 shows the five light rail lines (Eastside, Westside, Airport, Interstate, and I-205) and the commuter rail transit line (Westside Express Service/WES) that went into service before 2010 in suburban Portland. The 15-mile Eastside line was open in 1986 and connects downtown Portland with the city of Gresham; the 18-mile Westside line opened in 1998 and runs from downtown Portland to west portion of the Portland region; the 5.5-mile Airport line is an extension of the Eastside line to the Portland International Airport and its service began in 2001; the 5.8-mile Interstate line went into service in 2004 and serves north Portland; the 6.5-mile I-205 line opened in 2009 and runs parallel to the Freeway I-205; the 14.7-mile Westside Express Service (WES) is a commuter rail line that started service in 2009 and connects the Westside light rail line to south Portland (see Dong, 2016 for more detailed descriptions of these six rail transit lines). Rail transit lines and stations installed in and after 2010 were not considered to allow enough time to observe neighborhood changes. I use one-half-mile buffer zones around rail transit stops to define their service areas. Because this research relies on Census data to gauge neighborhood changes, I define neighborhoods based on Census block groups, the finest spatial scale at which reliable Census data are available for this analysis. A rail-transit-served neighborhood is defined as a neighborhood with at least a quarter of its area within a half mile of a rail transit stop.

This analysis focuses on neighborhoods in suburban Portland. It excludes downtown neighborhoods because almost all neighborhoods in downtown Portland have access to rail transit and it is difficult to find appropriate control neighborhoods for them. Portland's streetcar is not considered because it mainly serves downtown neighborhoods. Table 1 presents the number of suburban neighborhoods (block groups) that are served by rail transit lines installed before 2010.

3.3. Measuring gentrification and home affordability

This study uses decennial Census data and the American Community Survey (ACS) data to measure neighborhood changes. Specific data sources include Census 1990, Census 2000, ACS 2005–2009 (hereafter referred to as ACS 2009), and ACS 2010–2014 (hereafter referred to as

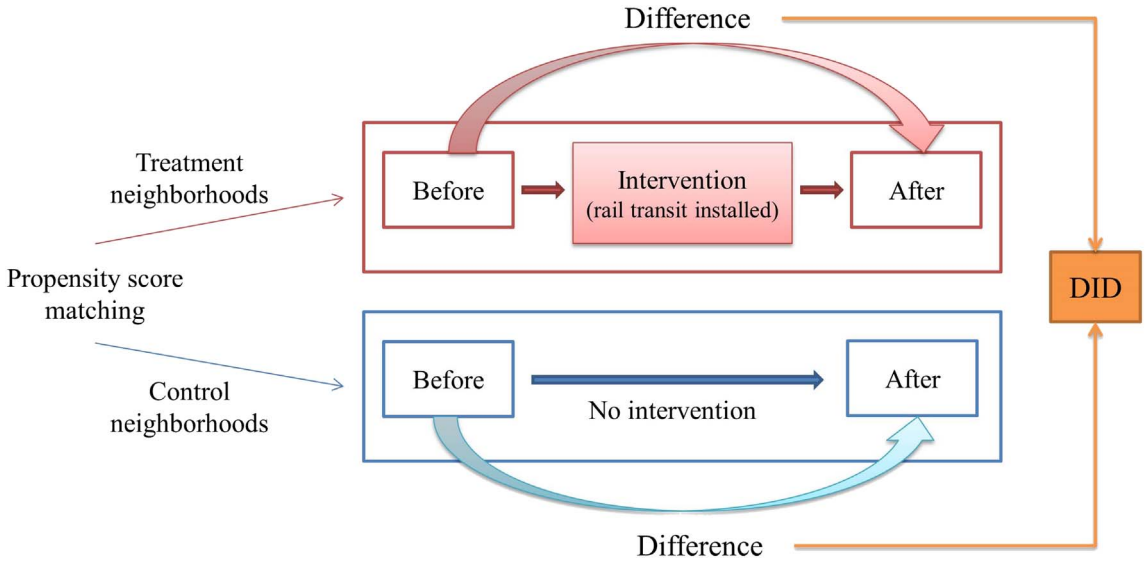

Fig. 1. Longitudinal quasi-experimental design.

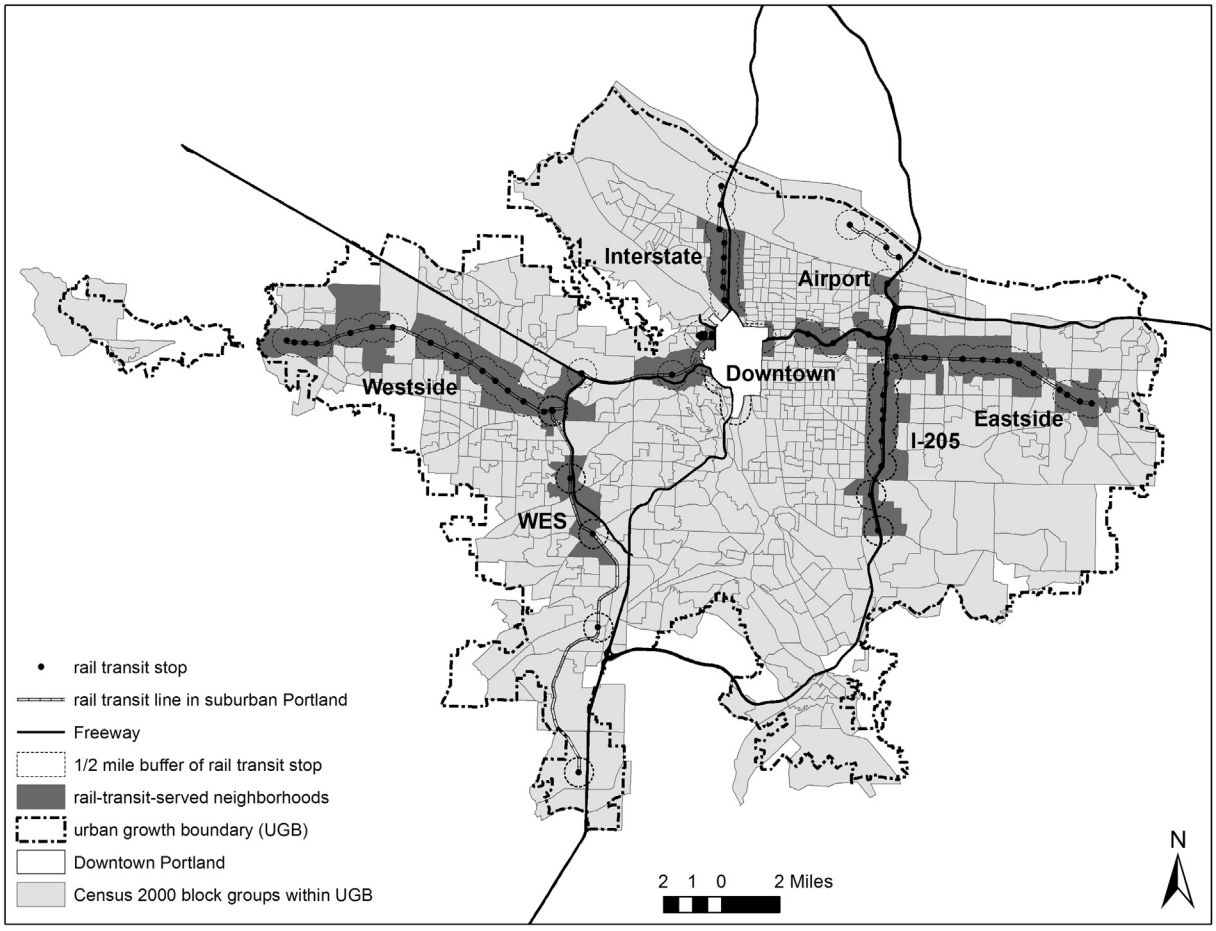

Fig. 2. Rail transit in suburban Portland.

Table 1
Number of suburban neighborhoods served by rail transit in Portland.

Rail transit lines open before 2010	Open	# of suburban neighborhoods served (in Census years)			
		1990	2000	2005–2009	2010–2014
Eastside	1986	58			
Westside	1998	0	39		
Airport	2001	0		30	
Interstate	2004				
I-205	2009	0			35
WES	2009				

Note: Streetcar and the transit mall opened in 2000 are not considered because they mainly serves downtown Portland.

ACS 2014). To make consistent comparisons between the four time points, data from Census 1990 and ACS 2014 are interpolated to Census 2000 block groups through the process of recombining block groups that had split and splitting block groups that had combined based on parcel-level housing data.

As discussed earlier, previous studies have measured and identified gentrification based on one or more of the following four basic factors: the sociodemographic characteristics of neighborhood, the physical, occupancy, and financial characteristics of the building stock, the specific number and characteristics of neighborhood newcomers, and the physical and capital investment flows into and out of neighborhoods (Landis, 2016). I adopt the first two factors to measure and identify gentrification in rail-transit-served neighborhoods. As shown in Table 2, I have five variables to measure the demographic changes of each neighborhood: 1) median household income; 2) the share of minority population; 3) the share of young population measured as the share of people aged between 25 and 39; 4) the share of small-sized households measured as the share of households with 1–2 persons; and 5) educational attainment measured as the share of adults aged 25 or more who have at least some college education. While the share of residents in professional or managerial occupations was also used in previous studies to measure gentrification, it is not included in this analysis because the U.S. Census changed their categorization of different occupations after Census 1990, making occupational data in Census 1990 incomparable to the data in later years. I use the following variables to measure the changes of the housing stock in each neighborhood: 1) housing tenure measured as the share of rental units; 2) home size measured as the share of housing units with two or less bedrooms; 3) median housing value; and 4) unit structure measured as the share of detached single-family homes.

In addition, I control for the distance from each neighborhood to the nearest highway ramp for two reasons. First, it helps control for the effect of highway accessibility. Second, almost all the rail transit lines in suburban Portland run parallel to freeways for the congestion-relief purpose (see Fig. 2). I also have three variables to represent the geographic location of a neighborhood: its distance to the city center (represented by the location of the Portland city hall), the county in which it locates, and its relative location to Portland's urban growth boundary (UGB). Improvement of employment accessibility is another factor through which rail transit can trigger neighborhood changes. Historical data of employment accessibility via transit in the Portland region, however, are not available for this study. I thus use distance to the city center as a proxy variable to represent employment accessibility of each neighborhood while acknowledging that this proxy variable may not be able to capture all the variation of employment accessibility via transit between studied neighborhoods.

Table 2
Variables to measure neighborhood characteristics.

Variable	Definition
Demographic composition	
Income	Median household income (adjusted to 2000 value, in $1000)
Minority	Share of black and Hispanic population (%)
Age	Share of young people aged 25–39 (%)
Household size	Share of small-sized households (1–2 persons) (%)
Education	Share of adults (25 +) with at least some college education (%)
Housing characteristics	
Tenure	Share of rental units (%)
House size	Share of small-sized units with 0–2 bedrooms (%)
Home value	Median housing value (adjusted to 2000 value, in $1000)
Unit structure	Share of detached single-family homes (%)
Home unaffordability	
Home unaffordability (renter)	Share of rental units with gross rent > 30% of household income (%)
Home unaffordability (owner with a mortgage)	Share of owned units (with mortgages) with owner cost > 30% household income (%)
Home unaffordability (owner without a mortgage)	Share of owned units (without mortgages) with owner cost > 30% household income (%)
Location	
Distance to freeway	Distance to the nearest freeway ramp (in miles)
Distance to city center	Distance to city center (in miles)
County	Located in Clackamas, Multnomah, or Washington (yes = 1)
UGB	Within the urban growth boundary (UGB) (yes = 1)

I treat the changes of home affordability as an outcome of neighborhood gentrification. A home unaffordability index is calculated for each neighborhood as the share of households who pay > 30% of their income for rent or owner costs. The U.S. Department of Housing and Urban Development (HUD) uses the 30% of income standard to measure affordability for the Section 8 voucher and certificate programs (Bogdon and Can, 1997). Landlords and mortgage companies also widely use this approach to evaluating their customers' ability to pay their rent or mortgages. This analysis differentiates three types of households: tenant households, home owners with mortgages, and home owners without mortgages. For home owners, owner costs are the sum of payment for mortgages, deeds of trust, contracts to purchase, or similar debts on the property, real estate taxes, various insurances, utilities, fuels, mobile home costs, and condominium fees. For tenants, rental costs include the amount of the contract rent plus the estimated average monthly cost of utilities and fuels if these are paid for by the renter.

3.4. Control selection and propensity score matching

As shown in Table 1, rail transit lines in Portland went into operation in several different years. I categorize the neighborhoods they serve into four treatment groups by Census year to match them to the Census data. The first one includes 58 suburban neighborhoods that have been served by the Eastside line since 1986; the second consists of 39 suburban neighborhoods that have been served by the Westside line since 1998; the third has 30 suburban neighborhoods that have been served by the rail transit lines installed in 2001 and 2004; and the last one includes 35 suburban neighborhoods that have been served by the two rail transit lines installed in 2009. The first two treatment groups were observed four times (in 1990, 2000, 2009, and 2014), the third group was observed three times (in 2000, 2009, and 2014), and the last one was observed two times (in 2000 and 2014).

Control neighborhoods are selected from suburban neighborhoods that had never been served by rail transit by 2010. Specifically, for the treatment group served by the Westside line (installed in 1998), a control group is identified based on their pretest neighborhood characteristics in 1990. For the two treatment groups served by the rail lines installed after 2000, their corresponding control groups are identified by their pretest neighborhood characteristics in 2000. Because reliable data at the block group level before 1990 are not available for this study, I use neighborhood characteristics in 1990 to estimate a control group for the treatment group served by the Eastside line installed in 1986.

Control neighborhoods are identified by one-on-one propensity score matching through the MatchIt package in the open-source statistical software R (Ho et al., 2011). One-on-one Propensity score matching is a statistical technique that entails forming matched sets of treated and untreated subjects who share a similar value of the propensity score. The MatchIt package provides several different matching methods. I choose the nearest neighborhood method because it results in the lowest mean differences between treatment and control groups. Nearest neighbor matching is done using a distance measure specified by a logistic regression model, which is used to estimate the propensity score, defined as the probability of receiving treatment conditional on the covariates. The variables that I use to estimate the propensity score include the sociodemographic, housing, and locational characteristics of the neighborhoods in their pretest years (see Table 3 for a list of these variables). This is to make sure that the treated and control neighborhoods had similar initial neighborhood conditions and similar tendency toward gentrification at the outset. As shown in Table 3, the four pairs of treatment and control groups are almost perfectly matched: their initial sociodemographic, housing, and locational characteristics are statistically the same. I also run separate logit models for the four treatment groups to understand how the variables discussed above predict treatment. The McFadden's pseudo-R-squared values are 0.19, 0.36, 0.37, and 0.46 for the neighborhood groups that are treated by the Eastside line, the Westside line, the lines went into service between 2001 and 2004, and the lines opened in 2009, respectively.

3.5. Compare treatment and control groups

I make pretest-posttest comparisons between the treatment and control groups through *t*-tests to assess the impacts of rail transit on nearby neighborhoods. This operation removes two potential sources of biases in second-period comparisons between the treatment and control groups: biases from their permanent differences and biases caused by time trends. The comparison results are presented in Tables 4 and 5. Table 4 focuses on the Eastside and Westside lines, using year 1990 as the pretest year. Table 5 focuses on the rail lines installed after 2000, using year 2000 as the pretest year. As shown in Tables 4 and 5, I compare each pair of treatment and control groups based on their neighborhood changes after rail transit was installed. For each neighborhood characteristic, its average change in the control group is

Table 3
Matching treated and control neighborhoods.

Matching variable	Eastside line (in 1990)			Westside line (in 1990)			Lines open 2001–04 (in 2000)			Lines open 2009 (in 2000)		
	trt.	ctr.	diff.	trt.	ctr.	diff.	trt.	ctr.	diff.	trt.	ctr.	diff.
Income	35.9	36.4	− 0.5	43.6	44.3	− 0.7	36.3	37.6	− 1.2	38.2	36.1	2.0
Minority	5.9	6.1	− 0.2	9.9	6.7	3.1	27.9	23.8	4.1	13.4	16.1	− 2.7
Age	27.9	26.8	1.0	31.5	31.4	0.2	26.4	25.8	0.7	25.5	26.4	− 0.9
Household size	64.9	64.3	0.5	66.3	67.2	− 0.9	62.6	63.1	− 0.5	59.4	59.2	0.2
Education	53.3	51.5	1.8	62.7	67.2	− 4.5	53.7	53.1	0.6	50.4	50.0	0.3
Tenure	50.7	47.8	2.9	58.2	57.7	0.5	39.8	35.3	4.4	46.9	50.3	− 3.4
House size	53.3	50.8	2.4	55.1	54.7	0.4	52.3	51.2	1.1	51.5	54.2	− 2.7
Home value	85.5	84.8	0.7	130.3	134.2	− 3.9	126.1	125.7	0.4	140.6	136.3	4.3
Unit structure	56.2	59.0	− 2.8	44.6	43.7	0.9	75.0	79.3	− 4.4	60.2	56.0	4.2
Distance to freeway	1.2	1.2	0.0	1.9	1.7	0.2	n.a.			0.5	0.6	− 0.1
Distance to CBD	7.0	6.9	0.1	8.6	8.6	− 0.1	3.9	4.4	− 0.5	6.2	6.3	− 0.1
N	58			39			30			35		

Note: trt. = treatment group; ctr. = control group; diff. = difference; none of the differences is statistically significant at the 5% or lower levels; control neighborhoods are also required to be within the UGB and in the same counties as their corresponding treated neighborhoods. We did not include "distance to freeway" for the lines open in 2001–04 because it significantly reduces the choice set of control neighborhoods, making it extremely difficult to find similar neighborhoods for the treated neighborhoods.

subtracted from the average change in the treatment group (refer to as "difference in difference" in Tables 4, and 5).

3.6. Compare treatment group and average neighborhoods

I also compare each treatment group with all the suburban neighborhoods that had never been served by rail transit (hereafter referred to as "average" neighborhoods. They were also referred to as "other" or "typical" neighborhoods in previous studies). Because the assignment of rail transit service is not random, trail-transit-served neighborhood are likely to differ systematically from average neighborhoods in the region. Average neighborhoods are thus not appropriate controls for quasi-experimental analysis (Cao et al., 2010; Kahn, 2007). With this in mind, I make this additional comparison to show whether and how rail-transit-served neighborhoods were different from average neighborhoods in the region before and after the installation of rail transit. The results of the comparisons between treated neighborhoods and average neighborhoods are also presented in Tables 4 and 5.

4. Analysis results

4.1. Transit-induced gentrification

I first assess the impacts of rail transit service on demographic and housing characteristics in rail-transit-served neighborhoods to evaluate the existence of transit-induced gentrification in suburban Portland. Due to space limitations, the following discussion focuses on four key variables that are widely used in the literature to identify gentrification: household income, share of minority population, home value, and housing tenure.

4.1.1. Household income

Comparisons between the treatment and control neighborhoods give mixed results regarding the association between the provision of rail transit and income changes in rail-transit-served neighborhoods in suburban Portland. The Westside line and the two lines that went into service in 2001 and 2004 did not show significant effects on household income in nearby neighborhoods they serve. Household income declined faster in the neighborhoods served by the Eastside line than in their control neighborhoods between 1990 and 2009. But such a faster decline is temporary and turns statistically insignificant after the observation period is extended from 2009 to 2014. Household income declined significantly faster in the neighborhoods served by the rail lines that started service in 2009 than in their control neighborhoods. Therefore, there is no evidence to suggest that the provision of rail transit service was associated with income increase. If there is any, it is the opposite: the introduction of some rail transit lines in suburban Portland was associated with income decline.

Comparisons between rail-transit-served neighborhoods and average neighborhoods in suburban Portland show that rail transit lines were built along lower-income neighborhoods. After the introduction of rail transit service, household income in nearby neighborhoods remained significantly lower than the regional average. Compared with average suburban neighborhoods, income growth was slower in the neighborhoods served by the Eastside line and the lines that went into operation in 2009, but faster in neighborhoods served by the lines installed in 2001 and 2004. Income growth in the neighborhoods served by the Westside line is not statistically different from the regional average.

4.1.2. Minority population

Rail transit did not show significant effects on the shares of minority population in their nearby neighborhoods in suburban Portland, except for the Westside line. Neighborhoods served by the Westside line saw significantly faster growth in the shares of minority population than their control neighborhoods between 1990 and 2014.

In comparison to average suburban neighborhoods, neighborhoods served by the Eastside and Westside lines had quite similar shares of minority population at the outset. Neighborhoods served by the rail lines installed after 2000 had significantly higher shares of minority population than average suburban neighborhoods in 2000. The shares of minority population in neighborhoods served by rail lines installed before 2000 and in 2009 grew much faster than the regional average after rail transit was installed. Neighborhoods served by the two lines installed in 2001 and 2004, however, saw significant declines in the shares of minority population, which is in contrast to the general increase of minority population in average suburban neighborhoods.

4.1.3. Home value

Rail transit that started service before 2000 did not show significant effects on home values in nearby neighborhoods that they serve. The two lines that opened in 2001 and 2004 showed a negative effect on home values between 2000 and 2009, but such an effect turned statistically insignificant when the observation period was extended from 2009 to 2014. The lines that opened in 2009 seemed to have a significant and negative effect on home values in nearby neighborhoods.

Compared with the regional average, median home values in rail-transit-served neighborhoods grew significantly slower between their initial years and 2014. Exceptions are the neighborhoods served by the two lines installed in 2001 and 2004, where home values grew faster

Table 4
Neighborhood changes 1990–2014 (the Eastside and Westside lines).

Variable	Eastside line					Westside				
	Change since 1990			diff. in diff.		Change since 1990			diff. in diff.	
	trt.	ctr.	avg.	trt. vs. ctr.	trt. vs. avg.	trt.	ctr.	avg.	trt. vs. ctr.	trt. vs. avg.
Household income (2000 value, in $1000)										
1990–2000	1.96	3.34	4.07	−1.38	−2.11	1.24	2.80	4.07	−1.56	−2.83
1990–2009	−0.58	3.86	4.45	−4.44*	−5.02**	0.65	0.19	4.45	0.47	−3.79
1990–2014	−2.11	1.04	1.69	−3.15	−3.80*	−1.11	−1.90	1.69	0.79	−2.80
Minority (share of Blacks and Hispnaics, %)										
1990–2000	8.19	5.85	3.27	2.34	4.92**	10.48	5.77	3.27	4.71*	7.21**
1990–2009	13.52	13.54	5.11	−0.01	8.42**	15.10	9.17	5.11	5.94	10.00**
1990–2014	13.40	10.17	5.80	3.23	7.60**	18.40	9.82	5.80	8.57**	12.60**
Age (share of persons aged 25–39, %)										
1990–2000	−2.19	−1.30	−3.51	−0.89	1.33**	−0.46	−2.09	−3.51	1.63	3.05**
1990–2009	−1.37	0.32	−3.34	−1.69	1.97*	−2.28	−1.22	−3.34	−1.06	1.06
1990–2014	−2.69	1.21	−4.24	−3.91**	1.54	−1.01	−5.04	−4.24	4.03*	3.22*
Household size (share of households with 1–2 persons, %)										
1990–2000	−1.34	−2.00	2.20	0.66	−3.54**	−3.68	−0.68	2.20	−3.00	−5.88**
1990–2009	3.14	0.85	5.73	2.29	−2.59	−0.20	−0.48	5.73	0.28	−5.93**
1990–2014	−1.29	−0.48	4.53	−0.81	−5.83**	−3.45	0.42	4.53	−3.88	−7.98**
Education (share of persons with at least some college education, %)										
1990–2000	0.69	6.20	6.74	−5.51**	−6.05**	1.28	4.68	6.74	−3.40	−5.46**
1990–2009	4.26	10.20	10.21	−5.94*	−5.95**	0.83	5.80	10.21	−4.97	−9.38**
1990–2014	9.94	14.92	13.08	−4.98*	−3.14	4.80	7.29	13.08	−2.49	−8.28**
House value (2000 value, in $1000)										
1990–2000	70.87	69.66	79.51	1.21	−8.64	88.57	77.26	79.51	11.31	9.06
1990–2009	121.02	132.71	151.67	−11.69	−30.65**	120.20	128.93	151.67	−8.73	−31.47*
1990–2014	87.53	104.90	117.37	−17.37	−29.84**	82.67	102.95	117.37	−20.28	−34.70**
Tenure (share of rental units, %)										
1990–2000	0.71	−2.85	−1.51	3.56*	2.22	−1.13	−1.33	−1.51	0.20	0.38
1990–2009	2.96	−0.83	−1.83	3.79	4.79**	−7.22	−2.99	−1.83	−4.23	5.39**
1990–2014	4.75	−0.97	0.26	5.72*	4.49**	−1.91	−2.15	0.26	0.24	−2.16
House size (share of units with 0–2 bedrooms, %)										
1990–2000	2.18	−0.27	−0.02	2.46	2.20	0.40	−0.78	−0.02	1.18	0.42
1990–2009	1.63	−3.57	−3.43	5.20*	5.06**	−5.19	−1.95	−3.43	−3.24	−1.76
1990–2014	−0.76	−3.89	−4.04	3.13	3.28	−5.18	−1.87	−4.04	−3.32	−1.14
Unit structure (share of detached single-family homes, %)										
1990–2000	−4.40	−0.05	−1.09	−4.35*	−3.31**	−1.35	−3.12	−1.09	1.77	−0.27
1990–2009	−7.53	0.40	−0.77	−7.93**	−6.76**	−3.15	−2.19	−0.77	−0.96	−2.39
1990–2014	−6.32	0.04	−1.55	−6.36*	−4.78**	−3.07	−2.41	−1.55	−0.66	−1.53
Home unaffordability: renter (share of rental units with gross rent > 30% of income, %)										
1990–2000	3.48	4.76	3.79	−1.28	−0.30	7.54	4.44	3.79	3.10	3.75
1990–2009	17.09	11.06	12.60	6.03	4.49	16.01	12.93	12.60	3.09	3.42
1990–2014	19.25	16.43	16.07	2.83	3.18	18.97	15.97	16.07	2.99	2.89
Home unaffordability: owner with a mortgage (share of owned units with owner cost > 30% income, %)										
1990–2000	13.34	9.87	10.78	3.47	2.56	5.39	10.05	10.78	−4.66	−5.38
1990–2009	25.88	18.40	19.37	7.48*	6.51*	17.71	17.30	19.37	0.41	−1.67
1990–2014	21.81	16.15	16.63	5.66	5.18*	10.17	17.26	16.63	−7.09	−6.46
Home unaffordability: owner without a mortgage (share of owned units with owner cost > 30% income, %)										
1990–2000	1.40	−2.22	−0.82	3.62	2.23	−4.24	−0.20	−0.82	−4.03	−3.41
1990–2009	3.29	9.47	3.99	−6.18	−0.70	−0.72	2.95	3.99	−3.67	−4.71
1990–2014	7.30	6.56	5.43	0.74	1.87	2.51	2.60	5.43	−0.09	−2.92

Note: *significant at the 5% or lower levels; **significant at the 1% or lower levels; trt. = treatment group; ctr. = control group; avg. = regional average; diff. = difference.

than the regional average from 2000 to 2014.

4.1.4. Housing tenure

The impact of rail transit on housing tenure structure was not statistically significant except in the neighborhoods served by the Eastside line, which saw a significant faster increase in the shares of rental units than their control neighborhoods. Compared with average suburban neighborhoods, rail-transit-served neighborhoods already had much higher shares of rental units in their initial years. This is consistent with the finding that rail transit was more likely to be installed along low-income neighborhoods in suburban Portland.

In addition to the four key variables discussed above, I also examine the changes of five other variables: age, household size, education, home size, and unit structure (see Tables 4 and 5 for details). There are two noteworthy findings and both of them are related to the Eastside line, the oldest rail transit line in the Portland region. First, compared with their control neighborhoods, neighborhoods served by the Eastside line saw declining shares of adult population with college education, suggesting that they had attracted less educated residents since the inception of the Eastside line. Second, neighborhoods served by the Eastside line were significantly associated with declining shares of single-family homes, indicating that they experienced densification in the study period.

Table 5
Neighborhood changes 2000–2014 (Lines installed after 2000).

Variable	Lines opened in 2001–2004					Lines opened in 2009				
	Change since 2000			diff. in diff.		Change since 2000			diff. in diff.	
	trt.	ctr.	avg.	trt. vs. ctr.	trt. vs. avg.	trt.	ctr.	avg.	trt. vs. ctr.	trt. vs. avg.
Household income (2000 value, in $1000)										
2000–2009	4.29	2.17	0.43	2.12	3.85					
2000–2014	2.72	2.50	− 2.45	0.22	5.17*	− 5.94	− 0.09	− 2.45	− 5.85**	− 3.49*
Minority (share of Blacks and Hispnaics, %)										
2000–2009	− 4.28	− 3.54	1.87	− 0.74	− 6.15**					
2000–2014	− 6.83	− 1.36	2.48	− 5.47	− 9.31**	9.38	6.82	2.48	2.57	6.90**
Age (share of persons aged 25–39, %)										
2000–2009	7.27	5.91	0.14	1.36	7.13**					
2000–2014	9.45	3.86	− 0.74	5.59**	10.19**	− 0.10	1.77	− 0.74	− 1.87	0.64
Household size (share of households with 1–2 persons, %)										
2000–2009	5.96	5.19	3.51	0.76	2.45					
2000–2014	5.09	1.75	2.40	3.35	2.69	1.01	4.63	2.40	− 3.62	− 1.39
Education (share of persons with at least some college education, %)										
2000–2009	14.60	10.53	3.46	4.07	11.14**					
2000–2014	21.81	19.97	6.39	1.84	15.42**	5.54	11.60	6.39	− 6.05	− 0.85
House value (2000 value, in $1000)										
2000–2009	91.27	68.17	72.13	23.10*	19.14					
2000–2014	79.28	60.96	38.23	18.33	41.05**	13.41	37.20	38.23	− 23.79**	− 24.83**
Tenure (share of rental units, %)										
2000–2009	− 2.32	0.75	− 0.36	− 3.07	− 1.96					
2000–2014	1.71	2.23	1.82	− 0.52	− 0.10	4.89	3.26	1.82	1.63	3.07
House size (share of units with 0–2 bedrooms, %)										
2000–2009	− 4.03	− 3.21	− 3.40	− 0.83	− 0.64					
2000–2014	− 3.54	− 6.60	− 4.01	3.06	0.47	− 1.62	− 4.22	− 4.01	2.60	2.39
Unit structure (share of detached single-family homes, %)										
2000–2009	− 1.19	− 3.21	0.34	2.02	− 1.53					
2000–2014	− 3.60	− 3.59	− 0.50	− 0.01	− 3.09	− 2.71	− 0.21	− 0.50	− 2.51	− 2.21
Home unaffordability: renter (share of rental units with gross rent > 30% of household income, %)										
2000–2009	4.81	12.14	8.48	− 7.33	− 3.67					
2000–2014	5.25	9.61	12.26	− 4.36	− 7.01	16.06	12.19	12.26	3.87	3.80
Home unaffordability: owner with a mortgage (share of owned units with owner cost > 30% household income, %)										
2000–2009	8.50	8.05	8.56	0.44	− 0.07					
2000–2014	0.42	0.05	5.84	0.37	− 5.41	8.91	3.53	5.84	5.38	3.07
Home unaffordability: owner without a mortgage (share of owned units with owner cost > 30% household income, %)										
2000–2009	9.94	11.56	4.75	− 1.62	5.19					
2000–2014	6.62	− 0.41	6.46	7.03	0.16	4.13	13.61	6.46	− 9.48	− 2.32

Note: *significant at the 5% or lower levels; **significant at the 1% or lower levels; trt. = treatment group; ctr. = control group; avg. = regional average; diff. = difference.

4.2. Home affordability

In this section, I evaluate the effects of rail transit on home (un) affordability for renters and homeowners (with and without mortgages).

4.2.1. Home affordability for renters

Changes of home affordability for renters were statistically the same between rail-transit-served neighborhoods and their control neighborhoods in the study period with no exceptions. This seems to suggest that rail transit did not make nearby neighborhoods less affordable for renters.

Tenant households in suburban rail-transit-served neighborhoods tended to pay higher shares of their incomes for rent than average households in suburban neighborhoods before rail transit was built. This is not surprising given that rail-transit-served neighborhoods tended to have lower income at the outset. Both rail-transit-served and average suburban neighborhoods saw dramatic declines of rental affordability in the study period, and the declines were roughly the same between them.

4.2.2. Home affordability for owners

There are no statistically significant differences between rail-transit-served neighborhoods and their control neighborhoods in terms of the changes of home affordability for owners in the entire study period, no matter they had mortgages or not. Neighborhoods served by the Eastside line saw faster declines in home affordability for owners with mortgages in the period of 1990–2009, but such a faster decline turned statistically insignificant when the study period is extended to 2014. In summary, rail transit did not show significant effects on home affordability for owners (with and without mortgages) in surrounding neighborhoods.

Both rail-transit-served neighborhoods and average neighborhoods in suburban Portland experienced declines of affordability for home owners in the study period. But the declines in the two groups of neighborhoods were statistically the same. The only exception is that home affordability declined faster in neighborhoods served by the Eastside line than average suburban neighborhoods for home owners with mortgages between 1990 and 2014.

The results of these analyses must be interpreted as a whole. One may argue that the changes of home affordability in the treatment and control groups could still be the same even if gentrification had

occurred in rail-transit-served neighborhoods. One possibility is that gentrification had occurred in rail-transit-served neighborhoods, both household income and housing cost had increased, but the proportion of income spent on housing had remained the same. This scenario is not supported by the data. As shown in Tables 4 and 5, the changes of household income in the first three treatment groups are not statistically different from their control groups between their pretest years and 2014. Household income in the fourth treatment group actually grew slower than its control group. The second possibility is that gentrification had occurred in rail-transit-served neighborhoods and existing low-income households had to suppress their housing consumption by moving into smaller homes to keep the share of housing expenditure in their budget constant. This scenario is not supported by the data either. As shown in Tables 4 and 5, the changes of home size are not statistically different between the four pairs of treatment and control groups, providing no evidence that households in transit-served neighborhoods had reduced their housing consumption in the study period. In summary, when we interpret the findings of this study as a whole, there is no consistent evidence for transit-induced gentrification and unaffordability in suburban Portland.

5. Conclusion

The positive effects of rail transit on property values and tax revenues are well documented and have been widely cited to justify the high cost of building rail transit infrastructure. The associated neighborhood and social effects of rail transit, however, are still understudied. With the expansion of the rail transit systems in American cities, there is an urgent need for a better understanding of the social effects of rail transit. This study contributes to the literature by evaluating whether rail transit in suburban Portland caused neighborhood gentrification and unaffordability through a longitudinal quasi-experimental design. I use the propensity score matching method to identify control neighborhoods and make pretest-posttest comparisons between the treatment and control neighborhoods at multiple observation points.

In general, I did not find consistent evidence for rail-transit-induced gentrification in suburban Portland. I did not find evidence that rail transit reduced home affordability for tenants and home owners either. I observed more changes in the neighborhoods served by the Eastside line (the oldest rail transit line in Portland) in the past three decades: socially, they attracted older and less-educated population than their control neighborhoods; physically, they experienced more densification and faster increases of rental units in their housing stock than their control neighborhoods. This seems to suggest that the effects of rail transit take a few decades to become apparent. I found that rail transit was more likely to be installed along low-income neighborhoods in suburban Portland, making their initial conditions different from typical neighborhoods in the region. This confirms the necessity of constructing appropriate control neighborhoods while evaluating the effects of rail transit on nearby neighborhoods.

The findings of this study are generally consistent with Kahn's study which also did not find evidence of transit-induced gentrification in Portland, Oregon (Kahn, 2007). They are, however, in contradiction to the studies that found signs of transit-induced gentrification in terms of income and housing cost in other American metropolitan areas (Immergluck, 2009; Pollack et al., 2010). The inconsistency could be due to different physical and temporal settings of the studies. The inconsistency could also be at least partially due to the different research approaches that are adopted. Instead of comparing rail-transit-served neighborhoods to appropriate control groups, Pollack's study makes comparisons between rail-transit-served neighborhoods with neighborhoods that are not served by transit in the region (Pollack et al., 2010). As shown in this study, these two groups of neighborhoods could already be very different before the introduction of transit service and a comparison between them is likely to be biased.

This analysis did not consider transportation costs while measuring home affordability, meaning that it might have underestimated the cost-saving benefits of rail transit. There is research showing that households living in neighborhoods with good public transit service tend to spend lower shares of their income on transportation costs (Hamidi et al., 2016). A recent national study reveals a paradox that whereas TOD neighborhoods are more expensive by housing costs, they are more affordable than hybrid and transit-adjacent-development neighborhoods because the lower transportation cost offsets housing costs (Renne et al., 2016). This study finds that rail-transit-served neighborhoods in suburban Portland are not statistically different from their control neighborhoods in terms of the changes of home affordability that is measured as the share of housing cost in household income. Rail-transit-served neighborhoods in suburban Portland, therefore, could be more affordable than similar neighborhoods that are not served by rail transit when savings in transportation costs are included when measuring home affordability. Unlike many previous studies (Ahlfeldt and Wendland, 2009; Duncan, 2011; Gibbons and Machin, 2005), this study did not find a significant positive effect of rail transit service on home values.

There are a few future research avenues given the limitations of existing studies, including this one. First, studies of the neighborhood and social effects of public transit are highly context-specific. Future studies in other metropolitan areas within and outside the United States will provide more comprehensive understanding of the neighborhood and social effects of rail transit. Public transit is used for only a small portion of daily trips in the United States. It seems sensible to expect public transit to have stronger social and neighborhood effects in metropolitan areas where transit has larger market shares. Second, in addition to access to transit, typical TOD design also features neighborhood characteristics that are in line with the new urbanist principles, such as compactness and mixed use. Future research may also explore the synergistic effects of public transit and new urbanist design in TOD neighborhoods. Lastly, data at the aggregate level precludes this analysis from exploring the inflow and outflow of individual residents and their social-demographic characteristics. Future research may conduct surveys that focus on individual residents in transit-served neighborhoods, especially those that move into and out of neighborhoods with the inception of rail transit. This study relies on an aggregate approach to measuring housing cost burden and has not differentiated households of different income levels. Surveys on individual residents will allow researchers to measure housing burden in a more accurate way.

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