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Rail station access and housing market resilience: Case studies of Atlanta, Baltimore and Portland

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Abstract
The recent United States housing market crisis resulted in a significant decline in housing market values. Yet, the extent to which urban amenities such as rail stations moderated the market impacts has not been entirely recognised. This study undertakes a repeat sales analysis to understand the impact of station proximity on housing values before, during and after the market crisis. Specifically, a housing price resilience index assesses market changes from 2002 to 2013 for single-family and multifamily homes within a quarter of a mile, half a mile, one mile and greater distances from the nearest rail station. The analysis is replicated in three cities: Atlanta, Georgia; Baltimore, Maryland; and Portland, Oregon. Although the recession had significant negative impacts on properties in each city, our study finds that access played a critical role in helping transit-orientated submarkets retain their value throughout the recession and recover value at a faster rate than homes without convenient fixed transit access.

Keywords
housing sales, price resiliency, rail stations, repeat sales analysis, transit accessibility

摘要
最近美国住房市场的危机导致房屋市场价值大幅下滑。然而，轨道交通站等城市设施缓和市场影响的程度尚未完全识别。本研究开展了回头客分析，以了解在市场危机之前、期间和之后轨道交通站的邻近度对住房价值的影响。具体而言，房价弹性能力指数评估了距离最近的轨道交通站四分之一英里、半英里、一英里和更远距离内的单户住宅和多户住宅从 2002 年到 2013 年的市场变化。这套分析被复制到三个城市中：佐治亚州亚特兰大、马里兰州巴尔的摩和俄勒冈州的波特兰。尽管经济衰退对每个城市的房产产生了显著的负面影响，但我们的研究发现，在帮助交通导向型区域在整个经济衰退期保持价值并以比没有方便的固定交通通道的房屋更快的速度恢复价值方面，轨道交通的通达性发挥了关键作用。

关键词
房屋销售、价格弹性、火车站、回头客分析、轨道交通通达性

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Introduction

Residential property values fluctuate over time. In the case of the recent ‘great recession’, property values suffered dramatic declines resulting in substantial losses to home owners and investors. However, the drop in housing values and resulting recovery was anything but uniform. Evidence indicates that large discrepancies existed in the rate of recovery and housing value across different urban spaces (Raymond et al., 2016). The list of factors responsible for this uneven recovery is both long and convoluted. However, built environment factors undoubtedly played a role in this outcome since a set of urban amenities influenced the rise of property values prior to the recession (Cheshire and Sheppard, 1995; Polinsky and Shavell, 1976; Smith, 1978; Tyrväinen and Miettinen, 2000). Fixed rail transit access is one of the most commonly theorised urban amenities to be capitalised within housing values. Although a substantial body of evidence traces the impact of rail station access on property values (Higgins and Kanaroglou, 2016; Mohammad et al., 2013; Zhong and Li, 2016), there is limited insight into how those properties whose value was impacted by fixed transit access fared leading up to, during and following the most recent housing market crisis.

The extent to which these factors influenced the rate of property value declines, the overall loss of value and the speed and magnitude of value recovery, which together reflect resilience in residential property values, has not been documented in planning research. As a significant public amenity that is known to impact property values in general, and that specifically may provide households with resilience to market and economic downturns by dampening mobility costs, this study focuses on fixed rail public transportation. The theoretical basis is that residents living in close proximity to fixed rail stations were able to devote a greater proportion of their household income to housing costs by reducing, or altogether eliminating, the cost of vehicle ownership due to their proximity to this amenity (Alonso, 1964; Mills, 1972; Muth, 1969). As a result, housing units in submarkets defined by strong transit access are hypothesised to depreciate in market value at a slower rate leading up to a housing crisis, to exhibit greater price stability during an economic recession and to recover at a faster rate than those housing units located in non-transit submarkets. In all, this effect is believed to be a result of capitalising transit access into property values (Welch et al., 2016), in which it is entirely possible that housing better served by public transit was more likely to remain attractive to potential buyers during the recent housing market downturn and subsequent recovery.

To test this hypothesis, a housing price resilience index derived from a repeat sales analysis was applied in three major American cities: Atlanta, Georgia; Baltimore, Maryland; and Portland, Oregon. The cities selected for these case studies are located in decidedly different housing markets as a result of their regional context, spatial structure and diversity in available transportation infrastructure. In these study areas, a set of residential submarkets located within distances of a quarter of a mile, half a mile, one mile and greater than one mile from a rail station, with

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multiple recorded housing sales between 2002 and 2013, was analysed to measure the property value resilience effects of fixed rail transit access. To this end, our study modelled housing sales data with a repeat sales index using a three-stage weighted regression with Fourier expansions to track the change in housing price appreciation as a factor of transit access. By implementing this methodologically innovative strategy, our study investigates the role of rail station access within these identified housing submarkets.

Literature review

Transportation infrastructure investments have been hypothesised to bring about a number of economic benefits. Most prominent within the literature as reviewed by Bhatta and Drennan (2003) are: output, productivity, production costs, income, property values, employment, real wages and rate of return. A well-studied benefit among this list is the contribution of transportation investments to residential property values. Among the studies on this investment–price relationship, the effects of light, heavy or commuter rail appear to be the most researched. Findings in this evidence base generally indicate that transit has a positive influence on residential property values and rents, although the estimated impacts seem relatively modest (Welch, 2010; Welch et al., 2016). However, variations in research approach and model specification among previous studies make drawing any firm conclusions a nearly impossible feat (Higgins and Kanaroglou, 2016).

Other studies have reported conflicting findings that proximity to transit does not necessarily lead to greater residential property appreciation rates (Bowes and Ihlanfeldt, 2001; Zhong and Li, 2016). Bowes and Ihlanfeldt's (2001) study of single-family housing sales within a quarter of a mile of Metropolitan Atlanta Rapid Transit Authority (MARTA) rail stations between 1991 and 1994 found a 19% discount in sale prices compared with those units located more than three miles from a station. A prior Atlanta-based study found that rail proximity increased residential property values in lower-income neighbourhoods, but had a contrasting effect on single-family homes in more affluent neighbourhoods (Nelson, 1992). A repeated argument of these and other studies has been that negative externalities arising from close station proximity, such as noise, traffic and personal security concerns, depressed housing sales prices (Bartholomew and Ewing, 2011; Chatman et al., 2012; Hess and Almeida, 2007).

The magnitude and rate of appreciation or depreciation attributed to transit proximity has also been a frequent topic of study. Knaap, Ding and Hopkins (2001), and earlier work by McDonald and Osuji (1995), found measurable increases in residential property value appreciation coinciding with the announcement of rail station locations, using the case of the then-planned light rail stations in Washington County, Oregon and the transit line from downtown Chicago to Midway Airport, respectively. Chatman, Tulach and Kim (2012) examined property prices along the River Line in New Jersey, during the planning, construction and operation stages of transit investment from 2000 to 2004. Study findings showed home value depreciation occurred during the post-groundbreaking stage, possibly owing to the nuisances caused by construction activities. A recent Los Angeles study by Zhong and Li (2016) found that from 2003 to 2004, multifamily properties located near established rail stations experienced higher rates of appreciation compared with single-family homes located within 400 metres of a new station, which lost approximately 26% in market value.

Dong (2015) examined whether single-family home prices in new urbanist neighbourhoods were more resilient during the great recession by analysing repeat single-family home sales in Portland, Oregon, during the housing price peak period (July 2006 to July 2008) and bottom period (July 2010 to July 2012). Study findings suggested that new urbanist design characteristics had a weak influence on housing price resilience. Interestingly, this study also suggested that proximity to a pre-existing light rail station had no significant impact on housing price resilience, and that single-family homes located within one mile of a newly opened light rail station exhibited price depreciation. However, the short-term nature of the study design inhibits the ability to determine if these reflect a lasting trend in the Portland housing market.

Previous investigations of the transit and property value relationship have provided inconsistent findings. Moreover, any generalisations of these findings are complicated by narrowed study area choices, limited temporal evidence and other methodological considerations related to model covariate selection and analytic technique. In response, this study examines the long-term impact of rail station proximity on housing sales prices in three diverse cities by constructing a repeat sales index that is less sensitive to any omitted variable bias (McMillen and Dombrow, 2001). To the best of our knowledge, this study represents the first investigation of housing price resilience during a national economic downturn or recovery as it relates exclusively to urban transit proximity.

Methods

Study area

Atlanta, Baltimore and Portland represent unique regional economic centres with varied spatial contexts and rail transit systems. Each city has developed under unique environmental and policy contexts, with wide variation in the service areas of their transit systems. Atlanta, with no natural boundaries, routinely ranks amongst the most sprawling metropolitan statistical areas (MSA) in the US. In terms of residential population, the City of Atlanta had an estimated 2013 population of 447,841 despite having a regional population greater than 5.5 million residents. This sprawling context contrasts with Baltimore and Portland, which both have higher residential populations within their city boundaries. Baltimore is the most compact and the oldest of the three case study locations. Although the city has higher levels of density, Baltimore has suffered from economic decline for several decades. In 2013, the end of our study timeframe, Baltimore had an estimated population of 622,104 and a metro population of 2.7 million, whereas Portland had a citywide and regional population of 609,456 and 2.3 million, respectively. While Portland falls between Baltimore and Atlanta in terms of density, the city has enforced an urban growth boundary for nearly four decades that has helped preserve it from urban sprawl conditions akin to Atlanta.

For this study, an attempt to reduce the existing spatial variation across MSAs was achieved by limiting each case study area to its legal municipal boundary. Baltimore and Portland are situated within a single county while Atlanta straddles two counties, with the bulk of transit stations in a single county. The counties that make up Atlanta, Fulton and DeKalb have a sprawl index value of 126.94 and 109.34, respectively. This is compared with Baltimore City's index value of 190.94 and Portland's Multnomah County, which has an index of 157.06. These index values have been centred at the value of100, so that index numbers above 100 indicate less sprawling locations. With a standard deviation of 25, these numbers suggest that each of the three cities have relatively similar land use patterns (Ewing and Hamidi, 2014).

In turn, the transit services in Atlanta, Baltimore and Portland reflect a diverse array of rail-based transportation options with varying levels of coverage and passenger ridership. The MARTA has 38 heavy rail stations spanning 48.1 miles of rail lines across the region, which supported 69.9 million unlinked passenger trips in 2013, the fewest reported annual trips since 2005 and a noticeable decline from the 86.0 million unlinked trips reported by MARTA in 2008. Baltimore has 14 heavy rail stations on 14.7 miles of track that supported 15 million passenger trips in addition to 33 light rail stations along 28.8 miles of rail, which provided another 8.6 million passenger trips. These annual ridership figures have been relatively unchanged since 2002, in which 13.9 million and 8.3 million unlinked passenger trips were taken by users of the Maryland Transit Administration's heavy and light rail services, respectively. In 2013, Portland's Metropolitan Area Express (MAX) amassed 38.3 million passenger trips on its system of four lines serving 87 light rail stations and spanning 53.9 miles of rail line. The MAX system was the only regional rail service to experience any network expansion over the study period, with the opening of the Yellow Line in 2004 and the Green Line in 2009. From 2002 to 2013, a 31.1 per cent increase in annual unlinked passenger trips has accompanied this service expansion.

Repeat sales data construction

To inspect the hypothesised relationship between rail access and housing price resilience, a large panel data set of housing sales observations with spatial calculations of transit station proximity was constructed. For each case study city, all single-family and multifamily residential sales recorded between 2002 and 2013 were collected using property assessor data for both Fulton and DeKalb counties in Atlanta, Maryland PropertyView data for Baltimore and Metro's Regional Land Information System database for Portland.

To construct the repeat sales data set, all residential parcels with only one observed sale were immediately discarded. All remaining parcels with an even number of sales over the observed period were then matched to minimise the elapsed time between housing sales. When an odd number of observations existed, the pairs closest together in time were matched and the odd remaining sale was then discarded. By minimising the time between repeated sales, the risk of an unobserved non-market factor (e.g. home renovations, new developments), which would influence year-to-year housing values, was reduced. The matching process resulted in the construction of a 12-year panel of 89,823 repeat housing sales pairs: 25,204 observations for Atlanta, 20,065 for Baltimore and 44,554 for Portland. Table 1 provides summary statistics for the observed repeat sales data. This summary table shows that sales are spaced out, on average, by about 3.5 years. The complete repeat sales data set is mapped for each city in Figure 1.

In order to systematically and uniformly study the influence of rail transit proximity on housing sales resilience, spatial information on the street network and station locations in each city was collected using the North American OpenStreetsMap (OSM) and General Transit Feed Specification (GTFS). The network distance between each housing location with a repeated sale during the study period and its closest rail station was calculated based on an A* shorted path algorithm (Zeng and Church, 2009) and segmented to define four levels of transit proximity: a quarter of a mile, half a mile, one mile and distances beyond one mile. Only observations of repeated residential sales and access to rail transit were required to specify the housing price and resilience index.

Table 1. Repeat sales analysis descriptive statistics by case study location and housing type.

Location	Housing type	Distance	Time between sales (years)					Price change between sales (US$1000s)					Transit distance (miles)				
			Min	Mean	Mdn	Max	SD	Min	Mean	Mdn	Max	SD	Min	Mean	Mdn	Max	SD
Atlanta	Multifamily	Quarter of a mile	1	2.53	2	11	1.74	−1100.00	−12.77	0.00	1813.97	217.86	0.00	0.02	0.00	0.25	0.06
		Half a mile	1	2.83	2	11	2.07	−1189.99	−25.74	0.00	850.00	214.66	0.25	0.33	0.33	0.40	0.04
		One mile	1	2.65	2	11	1.91	−1450.00	−18.90	0.00	1325.00	216.67	0.50	0.67	0.68	0.80	0.09
		Non-transit	1	2.19	2	11	1.52	−2250.00	−21.26	−15.00	2250.00	208.99	1.00	2.20	1.84	6.42	1.03
	Single-family	Quarter of a mile	1	3.71	3	11	2.43	−1055.45	−38.30	−19.00	1021.43	118.37	0.00	0.06	0.00	0.24	0.08
		Half a mile	1	3.87	3	11	2.57	−1189.99	−37.59	−12.00	830.00	125.31	0.25	0.35	0.35	0.40	0.04
		One mile	1	3.22	2	11	2.40	−1450.00	−35.05	−20.61	959.80	151.02	0.50	0.64	0.65	0.80	0.09
		Non-transit	1	3.28	3	11	2.39	−1250.50	−36.98	−23.20	1824.00	140.92	1.00	1.74	1.58	5.43	0.58
Baltimore	Multifamily	Quarter of a mile	1	3.65	3	11	2.20	−1842.09	58.24	53.00	1085.77	170.97	0.00	0.17	0.18	0.25	0.05
		Half a mile	1	3.52	3	11	2.24	−495.00	43.76	38.82	1660.00	120.77	0.25	0.33	0.33	0.40	0.04
		One mile	1	3.59	3	11	2.32	−1910.00	51.90	45.00	1205.00	138.48	0.50	0.65	0.65	0.80	0.09
		Non-transit	1	3.42	3	11	2.21	−1901.00	54.35	49.00	2362.50	137.43	1.00	2.54	2.15	8.82	1.33
	Single-family	Quarter of a mile	1	3.69	4	11	2.00	−1641.00	−37.01	−21.14	1630.00	245.53	0.00	0.17	0.19	0.25	0.06
		Half a mile	1	4.29	4	11	2.21	−1520.00	0.25	0.50	1440.00	159.75	0.25	0.33	0.33	0.40	0.04
		One mile	1	3.73	3	11	2.05	−1211.74	27.91	20.10	1795.00	182.95	0.50	0.62	0.59	0.80	0.08
		Non-transit	1	3.44	3	11	2.02	−2103.13	−26.64	−9.90	1546.00	185.91	1.00	2.07	1.55	7.65	1.17
Portland	Multifamily	Quarter of a mile	1	3.41	3	11	2.47	−238.04	32.28	41.00	284.90	89.29	0.00	0.01	0.00	0.25	0.05
		Half a mile	1	3.34	2	11	2.52	−205.85	64.08	66.90	327.00	93.05	0.25	0.32	0.33	0.40	0.04
		One mile	1	3.37	3	10	2.24	−340.00	44.03	44.14	390.00	99.57	0.50	0.64	0.64	0.80	0.09
		Non-transit	1	3.41	3	11	2.29	−453.00	41.58	49.75	925.00	96.44	1.00	2.43	2.32	5.64	0.94
	Single-family	Quarter of a mile	1	3.33	3	11	2.16	−944.38	21.01	29.00	545.83	94.25	0.00	0.05	0.00	0.25	0.09
		Half a mile	1	3.38	3	11	2.31	−590.00	29.38	33.00	426.00	103.50	0.25	0.33	0.34	0.40	0.04
		One mile	1	3.26	3	11	2.19	−492.40	36.81	30.50	671.00	100.38	0.50	0.67	0.68	0.80	0.09
		Non-transit	1	3.31	3	11	2.29	−860.00	42.56	40.00	925.00	91.28	1.00	1.88	1.68	5.32	0.75

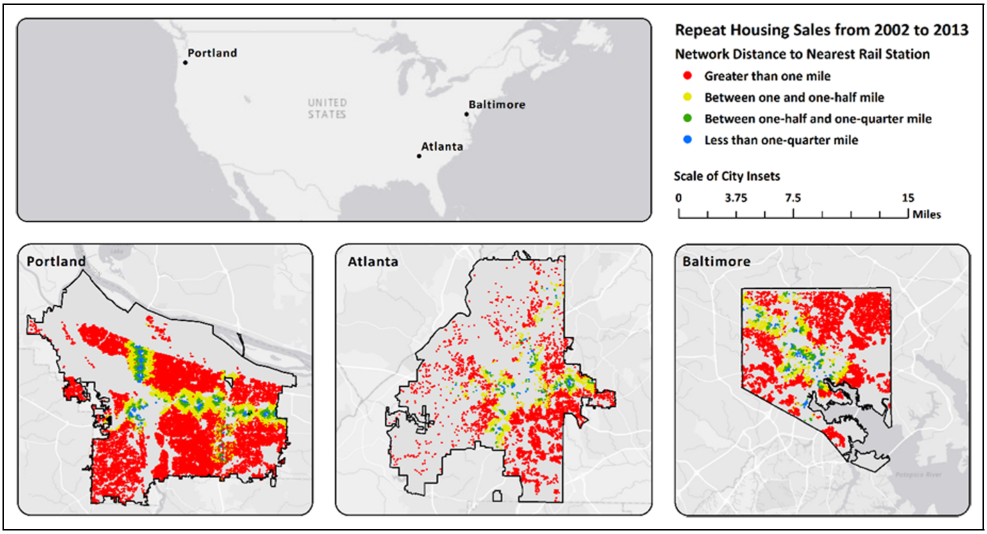

Figure 1. Rail station proximity for repeated housing sales locations from 2002 to 2013 for Atlanta, Baltimore and Portland.

Analytical approach

Measuring the magnitude and rate of change in housing prices is common in residential market analysis. While many analytic approaches exist, a frequently adopted method involves the development of an index of housing value. Arguably, the most common and perhaps most robust of these housing price indices is the repeat sales analysis (RSA) (Case et al., 1991). Repeat sales analysis was first developed in the 1960s (Bailey et al., 1963) as a method for creating a measure of average area-wide home prices and tracking year-to-year changes in value. The method did not gain substantial recognition until it was modified and generalised for the housing investment market during the late 1980s (Case and Shiller, 1987, 1989). The method is now used by Standard and Poor's Case-Shiller Home Price Index to measure the average annual change in housing sales prices across 20 United States metropolitan regions.

The Case-Shiller analytic method was adapted by Gatzlaff and Smith (1993) to measure the change in home prices for a local housing market due to a specific locational amenity. Gatzlaff and Smith (1993) measured the change by constructing two home price indices, one for a larger geographical area and a second for an area within a specific range of the locational attribute. The difference in the index levels was next compared, to find the change in home prices related to the locational attribute. This study follows the same procedure but with some modification.

The repeat sales index utilised in this study uses a three-stage weighted regression with Fourier expansions to treat time as a continuous variable (McMillen and Dombrow, 2001). Adoption of this complex methodology attempts to correct for the possibility of error with the passage of time between observed sales, resulting in heteroscedasticity. First, an ordinary least squares (OLS) regression is estimated, and then using the square of the first-stage residuals for the dependent variable in the third-stage regression. This strategy potentially corrects for three types of errors: any price variance over time, market mispricing and the random variance referred to as the Gaussian Random Walk. The RSA in this application is derived from a standard OLS regression model shown in equation (1):

$$p_i^t = \beta_i I_i^t + \beta_i E_i^t + \delta(T_i) + \varepsilon_i^t \qquad (1)$$

where p_i^t is the natural log of an observed sale price of residential property i at time t; I_i^t is a vector of internal explanatory variables specifying the characteristics of each residential property i at time t; E_i^t is a vector of external or neighbourhood characteristics associated with each residential property i at time t; $\delta(T_i)$ is a continuous time trend function for an observed residential property sale at price δ; and ε_i^t is an error term to capture the effects of unobserved variables (McMillen and Dombrow, 2001). This basic hedonic formulation for an observed sale is differenced to create a repeat-sales estimator:

$$Q_d^t = p_i^t - p_i^{t-1} = T_i^t - T_i^{t-1} + \varepsilon_i^t - \varepsilon_i^{t-1} \quad (2)$$

Where Q_d^t is the resulting price index level at time period t at distance band d from a transit station; p_i^t is the observed sale price of property i at time t the second observed property sale, $t-1$ the first observed sale and T the year of the observed sale; and ε is the error term of the effects of unobserved effects. We assume that internal and external factors do not significantly change between observed sales, thus the terms are dropped from the differenced repeat sales function. The resulting hedonic price function takes the form:

$$Q_{i,d}^t = T_i^t + \varepsilon_i^t \qquad (3)$$

Equation (3) is then estimated using a Fourier transformation by substituting T for a continuous smoothed function $\delta(T_i^t)$ such that

$$\delta(T_i^t) = \alpha_0 + \alpha_1 z_i^t + \alpha_2 z_i^{t,2} + \sum_{i=1}^{Q} \{\lambda_q \sin(q) + \gamma_q \cos(q z_i^t)\} \qquad (4)$$

where $z_i^t = 2\pi(T_i^t - \min(T_i^t))/\ (max(T_i^t) - \min(T_i^t))$, which allows for a flexible estimation when the underlying form of the functions are unknown. The final repeat sales model is:

$$Q_d^t = \delta(T_i^t) - \delta(T_i^{t-1}) = \alpha_1(z_i^t - z_i^{t-1}) + \alpha_2(z_i^{t,2} - z_i^{t-1,2}) + \sum_{i=1}^{Q} \{\lambda_q(\sin(qz_i) - \sin(qz_i^{t-1})) + \gamma_q(\cos(qz_i) - \cos(qz_i^{t-1}))\} + \varepsilon_i^t - \varepsilon_i^{t-1} \qquad (5)$$

The repeat sales analysis was performed across multiple iterations by dividing the data set by the three case study cities, then further distinguishing between single-family and owner-occupied multifamily units. To measure the impact of transit access on housing price resilience, repeat sales were divided into groups based on their network distance to rail stations. This stratification occurred for locations that were a quarter of a mile or less, greater than a quarter of a mile and less than half a mile, and greater than half a mile and no more than one mile from a rail station, as well as all locations greater than one mile from a transit station, which were defined as non-transit areas. As stated, Portland was the only city to expand its rail network during the study period. To address this issue, distance to the nearest transit station was measured at the time of the second observed housing sale. We hypothesise that distance at this second time period best captures the appreciation effects of transit proximity.

Finally, the resilience index (R-Index) was constructed with standardised scores of the price index for each location. Housing unit

Table 2. Model diagnostics of repeat sales analysis by case study location and housing type.

Location	Housing type	Distance	Adjusted R-squared	F-statistic	p-value	N
Atlanta	Multifamily	Quarter of a mile	0.214	273.569	0.000	4013
		Half a mile	0.162	80.953	0.000	1649
		One mile	0.086	52.903	0.000	2200
		Non-transit	0.118	189.892	0.000	5642
	Single-family	Quarter of a mile	0.030	11.989	0.000	1418
		Half a mile	0.022	2.526	0.041	275
		One mile	0.024	8.359	0.000	1181
		Non-transit	0.040	91.817	0.000	8826
Baltimore	Multifamily	Quarter of a mile	0.332	182.756	0.000	1461
		Half a mile	0.365	115.040	0.000	793
		One mile	0.316	314.677	0.000	2721
		Non-transit	0.326	1388.496	0.000	11,475
	Single-family	Quarter of a mile	0.431	70.125	0.000	365
		Half a mile	0.366	7.785	0.000	47
		One mile	0.423	48.801	0.000	261
		Non-transit	0.366	426.332	0.000	2942
Portland	Multifamily	Quarter of a mile	0.124	71.893	0.000	1998
		Half a mile	0.165	107.031	0.000	2142
		One mile	0.199	110.357	0.000	1759
		Non-transit	0.148	148.770	0.000	3411
	Single-family	Quarter of a mile	0.280	78.513	0.000	799
		Half a mile	0.257	124.472	0.000	1431
		One mile	0.193	273.748	0.000	4568
		Non-transit	0.228	2103.634	0.000	28,446

type and year price indices were compared against a similar price index constructed around the entire housing market to measure the difference from the entire market. The result from equation (3) is a composite index of values that range, in our study, between a possible score of – 3 to positive + 3. These scores represented the number of standard deviations a submarket index value was away from the rest of the housing market in a given year.

$$R_{l,d}^{t} = \frac{Q_{l,d}^{t} - \overline{Q_{l}^{t}}}{\sigma Q_{l}^{t}} \tag{3}$$

The R-Index provides a simple indication of how wildly prices in a submarket, in this case a major American city, and the level of transit access fluctuated from the rest of the city's housing market. R-Index values closer to zero indicate more stability in year-to-year changes in housing price appreciation or depreciation compared with the entire housing market of that city. Values greater than one indicate that the submarket out-performed the rest of the housing market, while values less than zero indicate that house prices dropped at a rate faster than the market.

Results

Separate models were estimated for the repeated sales of multifamily and single-family housing units located within the four distance bands in each of the three case study cities. Table 2 summarises the diagnostics of the 24 estimated models. Generally, the adjusted R-squared for each RSA model showed a reasonable level of explanatory power. Atlanta's single-family market was the one exception, although the p-values associated with each transit submarket

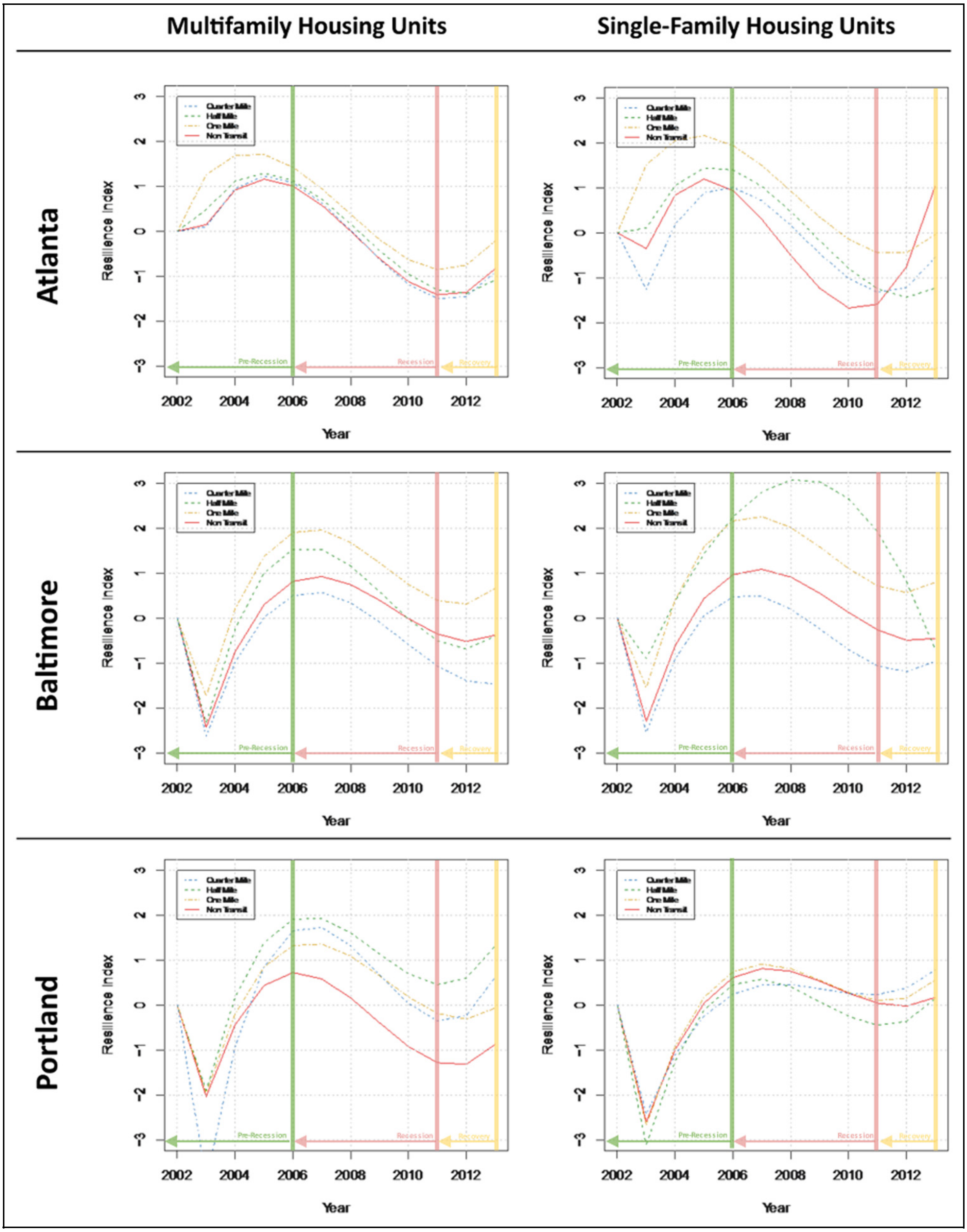

Figure 2. Housing price resilience index for multifamily and single-family housing units in Atlanta, Baltimore and Portland.

model were significant at the 95 per cent confidence level. This finding indicates that additional factors, aside from the time elapsed between sales and transit access, are likely to have influenced housing values in this housing market. Overall, the

Table 3. Single-family and multifamily housing resilience within transit and non-transit submarkets.

Location	Housing type	Distance	Repeat sales index				R-Index	
			t-test				Dispersion	
			Estimate	Lower CI	Upper CI	P-value	SD	IQR
Atlanta	Multi-family	Quarter of a mile	–5590	–7898	–3281	0.000	0.988	1.686
		Half a mile	–941	–4228	2347	0.542	0.994	1.802
		One mile	16,094	10,902	21,286	0.000	0.968	1.619
		Non-transit	–5170	–6893	–3446	0.000	0.931	1.569
	Single-family	Quarter of a mile	–8494	–20,358	3369	0.143	0.856	1.388
		Half a mile	1894	–13,130	16,918	0.787	1.054	1.940
		One mile	28,086	14,518	41,654	0.001	1.013	1.687
		Non-transit	–5314	–11,188	559	0.072	1.034	1.746
Baltimore	Multi-family	Quarter of a mile	–20,075	–26,791	–13,359	0.000	0.969	1.246
		Half a mile	4890	–1226	11,006	0.106	1.109	1.469
		One mile	25,863	20,205	31,522	0.000	1.030	1.164
		Non-transit	–3676	–5149	–2203	0.000	0.915	0.898
	Single-family	Quarter of a mile	–20,917	–27,533	–14,300	0.000	0.876	1.078
		Half a mile	54,987	32,894	77,081	0.000	1.450	2.414
		One mile	38,244	29,965	46,523	0.000	1.080	1.174
		Non-transit	–30	–539	480	0.900	0.935	1.108
Portland	Multi-family	Quarter of a mile	6539	–14,600	27,678	0.510	1.514	1.231
		Half a mile	41,348	29,860	52,836	0.000	1.060	1.057
		One mile	12,149	6787	17,511	0.000	0.921	1.099
		Non-transit	–23,794	–36,152	–11,436	0.001	0.863	1.243
	Single-family	Quarter of a mile	–1848	–8571	4874	0.557	0.885	0.455
		Half a mile	–11,574	–15,298	–7851	0.000	1.005	0.595
		One mile	2142	511	3773	0.015	0.988	0.528
		Non-transit	–1107	–2126	–87	0.036	0.940	0.561

predictive power of the remaining models is comparable to the parameters estimated in previous repeat sales analyses.

Figure 2 provides a graphical representation of the R-Index for single- and multifamily housing for all three study areas. The x-axes, which represent transaction year, may be evaluated based on the three major broad market phases covered in this analysis: pre-recession (2002–2006), recession (2007–2011) and recovery (2011–2012). As illustrated, the markets for single- and multifamily housing types fluctuate greatly in terms of appreciation as expressed through the estimated R-Index and the market-based responses to changes in network access to rail stations. Overall, properties located within a transit accessible housing submarket appreciated faster than non-transit locations. This effect is shown in Figure 2 where the curves for transit submarkets show a steeper upward trajectory (from 2002 to 2007, generally) and larger R-Index numbers. Further, transit-proximate submarket housing units held onto more of their value throughout the housing market crisis. This result is evident in the transit submarket curves within the post-2007 period, where higher R-Index values and flatter downward trajectories are plotted.

Transit submarket housing also recovered value faster when compared with the entire housing market, as shown in Figure 2 by steep upward trending curves with higher R-Index values after 2012. Table 3 reports the statistical significance of these findings via paired t-tests between each distance band and the broader housing market of each case study city. Table 3 also reports two dispersion measures, standard deviation and interquartile range, for the resilience indices across the various submarkets of Atlanta, Baltimore and Portland. Unlike the raw R-Index values portrayed in Figure 2, these two measures describe the level of stability for housing values across the 12-year study period. The following sections describe trends more specific to the three case study cities.

Case study: Atlanta, Georgia, USA

Atlanta's property began to lose value very early in the great recession, with relatively larger losses in value compared with Portland and Baltimore. This is likely a reflection of the nature of the city itself, a sprawling metropolis that was experiencing a significant housing boom prior to the recession. Single-family and multifamily housing units situated more than one mile from a rail station suffered a more significant loss in value in comparison with units with greater station access. Sold residences located between half a mile and one mile from a MARTA rail station tended to appreciate more and lost less value than the other transit submarkets, particularly for single-family housing units.

When comparing the performance of single and multifamily housing units in transit-accessible locations, there is little difference in price resilience. One exception, however, is the impact close proximity to a rail station, within a quarter of a mile, had on housing prices. Single-family housing units in this transit submarket underperformed in the years prior to the start of the great recession (2006), while multifamily housing units during the same period in the same submarket performed nearly identically to the broader non-transit multifamily housing sales market. These figures are indicative of the nature of the two types of housing stock, where single-family units located very close to transit stations are relatively scarce and perceived as being less desirable than multifamily units, which tend to favour transit-proximate locations.

During the recession, nearly every transit submarket unit inside Atlanta held its value better, by retaining more market value than non-transit housing units. The lone exception is for multifamily units within a quarter of a mile of transit, where housing prices dipped slightly lower than non-transit units. This is likely the result of greater pre-recession market speculation and a lower level of demand for these types of residences during the recession.

While no transit submarket has reached pre-recession housing values, multifamily housing units located between half a mile and one mile from the nearest station have nearly climbed back to 2002 values. Multifamily units sold in this submarket have continued to outperform multifamily units within the non-transit submarket. In contrast to Baltimore and Portland, the 2013 R-Index for single-family housing units is greatest for this non-transit submarket. However, the IQR for the one-mile transit submarket was lower than that for single-family homes without transit access, implying greater price stability for single-family homes located in the former distance band over the 12-year study period.

Case study: Baltimore, Maryland, USA

In Baltimore, single- and multifamily property located within a transit submarket further than half a mile from a transit station appreciated faster and held more value from 2002 to 2013. The significance of this differentiation in appreciation is tested in Table 3, showing that the change in housing value within these distance bands is statistically significant when compared with the movement of housing values in the rest of the city.

Those single-family units located between a quarter of a mile and half a mile of a transit station experienced a boom in market price leading up to the recession and halfway into the recession, until about 2009. After this point, prices began to fall rapidly, ending in levels below the general non-transit market levels by the end of the study period. This is the result of a reduced number of single-family units in Baltimore near transit stations, where the housing market is dominated by multifamily units. A slower rate of sales in this submarket led to longer-term price stability, but immediate price effects occurred when units began to turnover later in the recession. Single-family units between half a mile and one mile from a transit station largely mirrored the non-transit market in terms of price stability, with a greater number of units in this distance range; however, these units retained a greater market value over the entire study period.

Multifamily units located between a quarter of a mile and one mile from a transit station showed greater housing price resilience and market gains throughout the recession. Property in the quarter of a mile to half a mile range had a lower level of price instability and the market price was slightly below that of units in the non-transit market, ending with values just slightly lower than pre-recession levels.

Meanwhile, properties situated within a quarter of a mile of a station consistently fared worse than the rest of the housing market, which may highlight a potential nuisance effect associated with the closest level of station proximity and housing sales. Yet, as indicated by the IQR in Table 3, single-family housing units located in this transit submarket experienced more price stability throughout the recession when compared with other transit submarkets and non-transit locations. Therefore, rail transit access may indeed be a factor in providing some resilience to this housing submarket.

Case study: Portland, Oregon, USA

In Portland, single-family housing values over the study period were more stable than in either Baltimore or Atlanta. Single-family units located between half a mile and one mile of a MAX station reflected the only transit submarket to experience higher repeat sales values. In 2013, the R-Index for this transit submarket and those single-family housing units located within a quarter of a mile of a rail station outperformed the non-transit submarket, while the lower IQR for these transit submarkets showed their stability in year-to-year housing value changes. In turn, multifamily housing units located between a quarter of a mile and one mile from a station retained their value better during the recession and continue to sell for higher values than multifamily housing units within other submarkets. By 2013, these multifamily homes with good rail transit access were well above their 2003 R-index values and nearing the pre-recession levels of 2005.

Discussion

Each of our three case study cities showed unique patterns of housing price resilience across unit types and transit distance submarkets. Clearly, the context of each city and its transit system had a differing effect on housing sales; yet, while no single unifying pattern emerged, a more general effect was observed. Housing sales values were more resilient for properties with easy access to rail transit during the recent housing crisis. Throughout the downturn, properties located between a quarter of a mile and one mile from a station, with the exception of single-family homes in Portland, retained consistently higher sales compared with those properties located more than one mile from the nearest rail station. Over the 12-year study period, our estimated repeat sales indices revealed that single-family and multi-family homes located in this non-transit sub-market consistently experienced negative changes in housing value, with the exception of single-family homes in Baltimore. While our analysis uncovers these and other notable trends, the adopted methodology does not offer the specific evidence needed to explain why these effects occurred. However, we offer the following points of potential insight to address this.

First, transit station proximity may allow some homebuyers to for go vehicle ownership or reduce their dependence on a household vehicle for all travel. A resulting reduction in transportation costs would permit the prospective homebuyer to put the money saved on vehicle ownership and maintenance towards purchasing a comparable housing unit located closer to a rail transit station. Second, the lower monthly transportation costs associated with residing near a transit station may have reduced the travel-related budget of homeowners facing economic hardship. By reducing the cost burden of transportation, some households may have been able to better meet their monthly housing costs and keep their housing unit out of foreclosure. Third, the general desirability of housing with transit station proximity combined with the investment effects of transit station locations and co-location of employment opportunities may provide a healthier economic market in these places when compared with non-transit accessible locations. While not explicitly accounted for in this study design, a mixture of these factors and others are likely to also have provided greater housing price resilience throughout the recent American housing crisis.

Conclusions

This study is a first and novel approach towards measuring the contribution of transit access to housing sales resiliency. The relative impact of this oft-studied urban amenity was explored for three major US cities by using a housing price Resilience Index derived from analysis of repeated sales. Though the recent housing crisis had a significant negative impact on all properties located in Atlanta, Baltimore and Portland, our analysis showed that transit access played a critical role in helping transit submarkets retain their market value throughout the great recession.

In general, single-family and multifamily housing units sited between half a mile and one mile from the nearest station retained more of their value throughout the recent economic downturn than the rest of the city's housing market. In Atlanta, multifamily units in this submarket bounced back quicker than other transit and non-transit submarkets, while all housing units within this distance band in both Baltimore and Portland consistently displayed greater housing resilience than properties located farther than one mile from a station. Over the study's longer-term view, housing units in the three cities located more than one mile from the nearest station steadily experienced negative year-to-year changes in housing value.

While this study implemented a robust methodology and extensive panel data set to estimate a novel housing price resilience index, there are limitations to our analysis. Foremost, we did not specify a model that captured the effects of changes to housing units and the non-transit amenities between sales. While our construction of the panel data set reduced the likelihood of such factors biasing the estimated price indices, a possibility exists that in certain instances, particularly those where low R-squared values were obtained, an unspecified confounding set of factors may have influenced housing prices. This study also did not specifically control for the potential market impacts of rapid population growth between observed sales or changes in housing supply. These factors could potentially have an unobserved impact on housing prices. Additionally, while the use of three case study areas is a notable contribution, future work will focus on developing a richer data set to extend this analysis to additional cities that may either corroborate these market trends or provide new insight. Yet, despite these and other potential limitations, our study findings demonstrate that transit access had a positive impact on housing market resilience in Atlanta, Baltimore and Portland.

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