Characteristics of a Sufficient Statistic to Measure City Housing Prices

Daniel Broxterman*
Florida State University

William Larson†
US Department of the Treasury

Anthony Yezer‡
George Washington University

July 14, 2025

Abstract

For a variety of empirical purposes, it is important to be able to characterize the levels of and changes in housing price in cities, whether measured by rent or asset value. This task is complicated by the heterogeneity of the housing stock, the fact that neighborhood is consumed jointly with housing, and differences in accessibility. This paper concentrates on the issue of intra-city location which, based on economic theory, is systematically related to housing price. The final conclusion is that a sufficient statistic to describe both the level of and change in the average housing price requires that prices be measured as a function of distance from the city center and weighted by the fraction of the housing stock at each distance. Commonly used repeat sales and hedonic measures of price change are generally not weighted in this fashion, but could be modified to do so.

JEL Classifications: R14, R31
Keywords: housing price change, repeat sales, standard urban model

*Florida State University, Tallahassee, FL, USA (dbroxterman@fsu.edu)

†US Department of the Treasury, Washington, DC, USA (william.larson@ofr.treasury.gov). Views and opinions expressed are those of the authors and do not necessarily represent official positions or policy of the Office of Financial Research or the U.S. Department of the Treasury.

‡George Washington University, Washington, DC, USA (yezer@gwu.edu)

1 Introduction

Many market participants, researchers, and policy makers rely on index numbers to characterize the cost of housing in cities. Methods for constructing house price indexes vary substantially across and within countries, reflecting differences in intended use, data availability, and modeling strategy.

Among the various approaches, hedonic and repeat sales indexes are the two principal methods adopted in OECD countries to address the fundamental index number problem: separating changes in price from changes in housing quality over time. As reviewed in Section 2, a substantial literature has evaluated the strengths and limitations of these methods and proposed numerous data-driven refinements.

In contrast, this paper focuses on two important issues in index construction that arise from urban spatial theory and have received comparatively little attention. The first concerns the weighting of price changes across housing types and locations. Tenure status determines whether asset or rental values are observed, and tenure is not randomly distributed across urban space. Moreover, empirical research documents persistent spatial variation in appreciation rates within cities. Yet conventional indexes apply geographic and compositional weights only when aggregating subindexes to the national level, ignoring within-city heterogeneity that may bias estimates of local appreciation.

The second issue involves the choice of unit of analysis: whether indexes should track the price of housing units or housing space. The prevailing approach is to index housing units. However, because unit size varies systematically by location and over time, this decision can meaningfully affect inferences about affordability and price growth.

We consider whether a nonrandom sample of housing price changes can, under theoretically based conditions, sufficiently characterize the average rate of appreciation in a city. Conversely, if conventional approaches produce biased estimates due to spatial or compositional effects, we examine how alternative weighting strategies and unit definitions consistent with urban theory can reduce or eliminate this bias.

There is substantial evidence that housing price movements vary significantly by location within cities. In the US, for example, housing prices grew faster in central areas than in more suburban neighborhoods during the 2000s and 2010s, albeit with greater volatility. This pattern, which persisted through the pre-pandemic period, was not mean-reverting (Glaeser et al., 2012; Malone and Redfearn, 2018; Bogin et al., 2019a,b; Edlund et al., 2022). More recently, however, the COVID-19 pandemic disrupted this trend, shifting demand toward suburban areas with lower population density (Liu and Su, 2021; D'Lima et al., 2022).

Spatial heterogeneity in price dynamics also appears in response to specific shocks and policy changes. Infrastructure investments—such as new rail, highway, or bus facilities—affect the relationship between location and housing price appreciation in cities. Studies of oil price shocks have yielded mixed effects: while Molloy and Shan (2013) find that higher oil prices reduce development at the urban fringe rather than lowering housing prices there, subsequent research by Larson and Zhao (2020) cannot reject an inverse relationship between oil prices and relative housing prices in suburban areas. Monetary policy shocks can also produce highly localized effects, as demonstrated by Fischer et al. (2021).

The differential responses suggest variation in housing supply elasticity within metropolitan areas. Supporting this view, Baum-Snow and Han (2024) document substantial differences in both appreciation rate and supply elasticity across census tracts, using both hedonic and repeat sales measures. Their results are consistent with the theoretical implications developed here.

Further support comes from research on repeat sales indexes, which demonstrates that disaggregating the housing stock leads to meaningful differences in measured appreciation. For instance, Ambrose et al. (2023) show that rental price appreciation, measured using newly signed lease contracts, can diverge significantly from estimates based on surveys of existing tenants. Anenberg and Laufer (2017) find similar differences when constructing repeat sales indexes from contract rather than closing data. Contat and Larson (2024) develop tract-level repeat sales indexes and explore aggregation strategies for producing citywide measures.

This paper contributes to that line of inquiry by relating alternative aggregation schemes to theoretical models of intra-urban house price variation.

In addressing the spatial weighting of housing price levels or changes, it is also necessary to consider the definition of the index base. Two key dimensions of price variability are closely related to the issue of spatial distribution. The first is tenure status: rental prices are not observed for owner-occupied housing, and asset prices are not generally available for rental units. The second is unit size, which varies substantially across space, implying that price per room or square foot may diverge significantly from unit-level prices that do not account for size. Both dimensions complicate the construction of spatially aggregated price indexes, as the distribution of housing units by tenure and size is highly uneven within cities.

These considerations may justify constructing separate indexes for rental and owner-occupied housing or choosing between indexes based on unit prices versus those based on housing space. The appropriate approach is ultimately an empirical question that depends on city-specific characteristics, including the prevalence of rental housing and the degree of variation in unit size. Using publicly available data, this paper illustrates how these definitional choices affect housing price measures across US metropolitan areas. Although the empirical application focuses on the US, the core issues apply broadly to city-level index construction in other countries.

This paper makes three main contributions. First, it provides theoretical support—based on the standard monocentric city model of Alonso (1964), Mills (1967), and Muth (1969)—for the empirical observation that housing price appreciation exhibits systematic spatial variation within cities. Second, it extends prior work on spatial aggregation by incorporating heterogeneity in both tenure status and unit size, two dimensions that have received limited attention in the house price indexing literature. Third, it presents empirical examples using survey data on both renter and owner units and from central-city and suburban locations, along with tract-level repeat sales indexes to demonstrate how these factors affect measured rates of price change across metropolitan areas.

Consistent with expectations based on theory the demonstrations show that even modest changes in the approach to measuring city housing price changes can meaningfully affect measures rates of appreciation for specific cities.

The remainder of the paper is organized as follows. The next section reviews the strengths and limitations of hedonic and repeat sales indexes. Section 3 introduces the sufficient statistic conditions for a Laspeyres index, which motivate the proposition derived in Section 4 from the standard urban model that price changes should be modeled as a function of distance from the city center and weighted by the housing stock at each distance band. Deviations from this approach implicitly assume a model of urban form in which the income elasticity of housing demand is zero. Sections 5 and 6 present empirical comparisons using data from the American Housing Survey and the Federal Housing Finance Agency. These comparisons reveal substantial differences in appreciation by tenure and centrality. Section 7 concludes with implications for the empirical measurement of house price change.

2 Conventional housing price indexes

Constructing a price index requires comparing prices for identical items over time. In the context of real estate markets, this task presents two well-recognized challenges. The more fundamental of the two is that no two properties are identical, and many of the characteristics that affect price are incompletely observed. This makes it inherently difficult to control for the substantial cross-sectional heterogeneity in property attributes. A secondary challenge arises even when the same property is traded in multiple transactions: its price-determining attributes may evolve over time due to depreciation, renovation, or alteration. To isolate true price movements, the econometrician must account for both variation across properties and changes within properties over time.

2.1 Weighted repeat sales methodology

In the US, the most commonly used residential property price indexes implement the repeat sales methodology. A repeat sales index addresses the fundamental problem of unobserved heterogeneity by limiting comparisons to properties that have transacted more than once. By holding the unit constant, this approach differences out time-invariant characteristics, under the assumption that a property's quality remains stable between sales. The index is constructed by estimating a pooled regression on the observed price changes across all repeat transactions. Because the regression errors increase with the time interval between sales, modern implementations adjust for this heteroskedasticity.

[More detail to come on methods. Also, strengths, limitations, and weighting strategies from the literature.]

2.2 Hedonic regression methodology

Most developed countries other than the US rely primarily on hedonic price indexes rather than repeat sales methods. Provided that sufficiently detailed data on property characteristics are available, hedonic models can account for changes in quality at the property level, an issue that poses challenges for the repeat sales approach. While hedonic indexes can be constructed using time dummy coefficients from a pooled regression, the method preferred by national statistical agencies typically involves estimating predicted prices from the regression model and aggregating them to construct the index.

[More detail to come on methods. Also, strengths, limitations, and weighting strategies from the literature.]

3 Sufficient statistics for a Laspeyres index

Housing price measures can be based on either rental or asset prices and the basis of quantity measurement can be the housing unit or housing services provided, i.e., a measure

such as interior space which may be adjusted for quality. These details of measurement are consequential but not the focus of this paper. Regardless of the price or quantity measure chosen, the index number problems we identify are mathematically identical.

Laspeyres (1871) would answer the index number problem for measuring the average housing price and its rate of change by recognizing that price and quantity varies with location and constructing a price index treating housing in each location as a distinct good. Suppose that r_t^* is an index number indicating the average price per unit of housing at time t, and that housing at a distance k from the center city is homogeneous such that

$$r_t^* = \sum_k r_t(k)h_t(k) \Big/ H_t(k), \tag{1}$$

where $r_t(k)$ and $h_t(k)$ are, respectively, the price and quantity of housing at time t and distance k from the city center, and $H_t(k) = \sum_k h_t(k)$. The Laspeyres measure of the rate of change in housing price between $t-1$ and t is then

$$\frac{\Delta r_t^*}{r_{t-1}} = \frac{\sum_k r_t(k)h_{t-1}(k) \Big/ H_{t-1}(k)}{\sum_k r_{t-1}(k)h_{t-1}(k) \Big/ H_{t-1}(k)}. \tag{2}$$

The sufficient statistic implications of Equations (1) and (2) are demanding: The marginal distributions of both housing prices and quantities over various distances, k, must be known.

There are two assumptions that may simplify the computation of (2). First, if the percentage change in the price of housing is constant across all k, then $r_t(k)/r_{t-1}(k) = \theta$ and it follows from (2) that a sufficient statistic for measuring the rate of housing price increase is a measure of θ which may occur at any k (Contat and Larson, 2024). For example, in small cities with relatively flat appreciation gradients in many periods, this assumption may commonly hold. The spatial distribution of housing may vary, but it is not essential to the computation of a sufficient statistic for measurement of the percentage change in housing cost.

A second assumption may also yield the targeted Laspeyres index. If the weights used in the index construction are proportional to $h_{t-1}(k)/H_{t-1}(k)$, then the resulting index will be a Laspeyres index. For example, this circumstance can occur if an index is calculated using observed transactions, and transaction shares are proportional to housing stock shares.

The discussion thus far has assumed agreement on the fundamental nature of the housing good being priced. While it is common to construct indexes based on the price of housing units, this approach treat a highly heterogenous good as uniform. In particular, the quantity of space in housing units varies substantially over time and across location. If an the objective is to measure the price of housing services or housing space, then the definitions of h and H in the preceding equations should reflect a measure of housing services, rather than assuming that each housing unit provides the same quantity of housing space. The empirical examples in later sections will illustrate the importance of differences in weighting by measures of space and units.

4 Economic theory and sufficient housing price statistics

The previous section suggested that if the percentage change in housing price is not a function of distance, then measurement of housing price change does not require a spatially random measure of housing prices. In this case, it is not necessary to account for spatial differences in housing density or differences in location where housing price change is measured. Accordingly, the measurement of housing prices can be geographically concentrated. This section considers the relation between this assumption of constant rates of price change across space and standard urban economic theory. Specifically, under what circumstances is it reasonable to expect that the rate of change in house prices in cities is not a function of location.

In a neoclassical city, such as the classic monocentric model reviewed by Brueckner (1987),

households achieve an iso-utility equilibrium in which utility of a composite commodity, c, whose price is normalized to unity and constant throughout the city, and housing, h, with price, r, that varies with location, k. Households must either commute to a city center where they earn income, y, or commute shorter distances where they face an urban wage gradient which is reduced by the amount of commuting cost saved. Therefore, the households' problem is to

$$\max U(c,h) \text{ subject to } y - \tau k = c + r(k)h, \tag{3}$$

where τ is commuting cost per unit distance.

The iso-utility of households implies that $\mathrm{d}r/\mathrm{d}k$ is determined by Muth's (1969) equation requiring that $\mathrm{d}r/\mathrm{d}k = -(\mathrm{d}\tau/\mathrm{d}k)/h$. The only general constraint on $\mathrm{d}\tau/\mathrm{d}k$ is the logical requirement that it is greater than zero, however the further simplification that it is constant will be maintained here.[1] Housing consumption, h, is determined by the iso-utility condition and earnings.

The essential question of determining a sufficient statistic for measuring house price change reduces to a simple question: What constraint does Muth's equation and the requirement that $(\mathrm{d}r/\mathrm{d}k)/r = \text{constant} = \theta$ place on the housing demand function?

Dividing through Muth's equation by r yields

$$(\mathrm{d}r/\mathrm{d}k)/r = -(\mathrm{d}\tau/\mathrm{d}k)/rh. \tag{4}$$

But this implies that for both Muth's equation and $(\mathrm{d}r/\mathrm{d}k)/r = \text{constant} = \theta$ to hold, then

$$(\mathrm{d}r/\mathrm{d}k)/r = -(\mathrm{d}\tau/\mathrm{d}k)/rh = \theta. \tag{5}$$

Thus, for the percentage change in the rental price of housing to be constant across all

[1] The units of $\mathrm{d}\tau/\mathrm{d}k$ must be chosen so that they are consistent with the measurement of rental price. This issue has been discussed extensively in the literature. The simplification that this measure is not a function of location is adopted here because if that is not true, it would further complicate the measure of housing price differences as discussed below.

locations $k \leq k^*$ and be consistent with Muth's equation, the ratio of the marginal rise in transportation cost with distance to total housing expenditure must be constant.

Proposition 1. *If commuting cost per mile is constant and the iso-utility condition of households holds, constancy of the elasticity of housing price change with distance from the city center implies that the household utility function must be quasi-linear.*

Obviously if $\mathrm{d}\tau/\mathrm{d}k$ is constant, then total expenditure on housing must be constant. If the price of the composite commodity does not vary systematically with location, as is commonly assumed, this implies that the utility function of households takes a specific quasi-linear form,

$$U(c, h) = \lambda \ln h + \rho c. \tag{6}$$

Maximization of (6) as constrained in (3) produces a housing demand function in which

$$r(k)h(k) = \lambda/\rho, \tag{7}$$

which satisfies the criterion in (5) that both the marginal increase in commuting cost with distance and total housing expenditure do not vary with location. Thus, Proposition (1) is proved.

The difficulty with this result is that there is no evidence that preferences for housing are quasi-linear. There is debate in the empirical literature regarding where the income elasticity of demand for a primary residence lies on the interval from some positive value to unity, but agreement that the zero income elasticity of quasi-linear utility is inconsistent with all evidence.

Proposition 2. *The iso-utility assumption regarding urban households implies that a sufficient statistic for constructing a Laspeyres index of price change in a city requires that rates of price change be measured as a function of distance from the city center and weighted by the fraction of housing at each distance interval.*

This proposition follows directly from Proposition (1), the empirical evidence on demand for a primary residence, and the definition of a Laspeyres index from Equation (1) and so no proof is given.

5 Illustration of the effect of distance on measures of housing price change

In this section, we use the the American Housing Survey Metropolitan Sample (AHS-MS) to illustrate the potential effects of failing to consider location in constructing an index of city housing price changes. Both rental and asset prices are examined. Rental prices are important for measuring cost of living and value of current use, whereas asset prices also incorporate expectations and option value. For purposes of illustration, the AHS-MS is particularly convenient for multiple reasons. First, it surveys households in both renter and owner units and it classifies housing spatially into central-city and suburban locations. This allows comparison of price indexes by tenure status and centrality where differences are likely substantial. In addition, the AHS-MS is longitudinal so that price changes can be calculated based on the same units in the same locations over time.

Using AHS-MS data, we first measure changes in city house prices by calculating the annual growth rate in the median estimate of value and rent (reported in ranges) for all sample units in the metro area regardless of location. The results of this exercise are displayed in the first two columns of Table 1 for 25 US cities for the years 2015 to 2019. This was clearly a period of rapid growth in the price of housing. The median value of owner-occupied homes grew at a compound annual rate ranging from 1.4% to 13.6%, with an average of 7.1%. For median rent, the range was 1.6% to 7.9%, with an average of 4.8%.

What are the potential deficiencies of using the metrowide values in Table 1 to characterize housing price changes in the 25 cities covered? Like most large-scale surveys, AHS-MS is a stratified sample. The nine categories employed in the sampling strategy pertain mostly

to tenure and structure type, but not to location within the metro. Unfortunately, there is no reason to believe that the stratified samples are spatially random, because the sample rate for each stratum is constant while the fraction of units varies by location. In other words, the Census Bureau does not cross-stratify by location, e.g., (renter vs. owner) $\times$ (central city vs. suburbs). As explained in Section 3, variation in the spatial distribution of housing is only consequential if the percentage change in the price of housing is not constant across locations. Accordingly, we next examine growth rates of asset and rental prices in the AHS-MS separately for units located in the central city and suburbs.

Based on the literature cited in Section 1, we know that 2015 to 2019 was a period during which centrality had become a more sought-after amenity in many large cities. Therefore, our first hypothesis is that the growth rates of rental and asset prices displayed in Table 1 will be different when location is divided into central city and suburb. As expected, columns three through six show substantial differences in rates of change between these two broad areas of cities. While the suburbs did outperform in some metros, growth rates of value and rent in the central city were 137 and 15 basis points (BPS) higher on average, respectively, consistent with the pre-COVID urban resurgence narrative.

For our purposes, the estimates in Table 1 demonstrate that rates of appreciation are clearly not spatially invariant within cities. Taken to the logical extreme, if either central city or suburban samples were used alone to estimate the average rate of change for the entire city, the bias would be substantial. Of course, to the extent that sampling in the AHS-MS approaches the spatially randomized ideal, a weighted average of spatially varying changes should approximate the simple mean change rate for the entire city.

We next consider two alternative ways of characterizing housing price change at the metro level using annual growth rates in median value and rent from the AHS-MS. In the first construction, we simply average the rates for the central city and suburbs. Taken at face value, these naive indexes, which appear in the first two columns of Table 2, would indicate that the median value of owner-occupied homes grew at an average of 7.8% and rents by

5.4% in the 25 cities covered. These results can be compared with a Laspeyres index in columns three and four that weights the growth rates by all units, renter and owner, in each location as suggested by Proposition 2 in the previous section.

The Laspeyres index provides a useful reference point because it is consistent with other well known price index formulations. Differences between the Laspeyres and simple average indexes are in columns five and six of Table 2. On average, growth rates based on the Laspeyres (sufficient statistic) index are 43 and 4 BPS lower, respectively, in comparison with their simple average analogs. (Relative to the metrowide growth rates in Table 1, values for the Laspeyres indexes are 29 and 53 BPS higher.) For particular cities, the differences are much more substantial. For example, house price growth is 495 BPS lower in Atlanta and rent growth is 205 BPS lower in Pittsburgh using a Laspeyres index relative to a simple average of the central city and suburbs rates for those metros.

6 Illustration using repeat sales price estimates

The most common approach to measuring city-level asset price changes in the US is the weighted repeat sales index, which relies on panel data from actual transactions rather than owner-reported values, such as those provided by the AHS. Baum-Snow and Han (2024) offer a comprehensive review of the literature showing that repeat sales-based appreciation rates vary substantially across census tracts within the same city. They further demonstrate that estimates of housing price change and supply elasticity differ depending on whether they are based on housing units or interior space—findings consistent with the propositions advanced in this paper. Accordingly, standard city-level index construction (e.g. FHFA or Case-Shiller) using repeat-sales methods that aggregate all available transactions and then weight by the time between same-unit transactions is a scheme that is *ex ante* unlikely to be proportional to housing stock, and thus result in a Laspeyres index.

Separately, Contat and Larson (2024) provide tract-level estimates of housing price ap-

preciation for 63,122 census tracts across 581 core-based statistical areas from 1989 to 2021. We use these data to examine how location and alternative definitions of housing services affect observed patterns of asset price appreciation.

Compared to the AHS data in the previous section, the repeat sales estimates offer greater spatial disaggregation, enabling analysis based on location variables, including distance from the center city. However, they do not include rental price changes. Accordingly, the empirical illustration here focuses on how asset price appreciation responds to alternative aggregation schemes, without parallel comparisons for rent-based measures.

Census data provide information on the number of rental and owner-occupied units in each tract, as well as average unit size (in rooms) and reported value. Consequently, results for asset price change weighted by total number of units versus those weighted by only owner or only renter aggregations can be evaluated and compared with aggregations weighted by measures of unit size or value.

The general form of the city housing asset price computation is

$$\%\Delta P_{tj} = \sum_i W_{ijt} \%\Delta P_{it} \tag{8}$$

Where i is an index of Census tract, $\%\Delta P_{it}$ is the weighted repeat sales estimate of asset price for tract i in period t, and W_{ijt} is type j tract-based weight used to aggregate repeat sales estimates across the city. Formally, $W_{ijt} = J_{ijt-1} / \sum_i J_{it-1}$ where J is a measure of the tract weight based on one of five factors: total housing units, owner-occupied units only, rental units only, average number of rooms, or average asset value in tract i. Because the standard for repeat sales price indexes is based on owner occupied units only, this will be the baseline against which alternative aggregations are considered.

The effects of location and alternative measures of housing services are illustrated using examples from Boston and Houston. These cities represent opposite ends of the spectrum among large metropolitan areas in terms of rental share and land-use regulation. In Boston,

nearly 65% of the housing stock is renter-occupied, compared to about 40% in Houston. Boston also enforces more restrictive planning policies, while Houston is known for its minimal regulatory environment. Given these contrasts, we expect not only differences in appreciation rates by location and housing service measure within each city, but also distinct spatial and temporal patterns between them.

Figure 1 presents tract-level estimates of price appreciation for the full 1990-2020 period, as well as for two subperiods corresponding to the housing boom (2001-2006) and bust (2006-2011). The maps display census tracts with centroid located within a 15 mile radial distance of each city's City Hall. As expected, both cities exhibit substantial within-city variation in appreciation rates across census tracts across each time interval.

The temporal dynamics, however, differ markedly across the two cities. In Boston, the pattern is consistent with mean reversion: tracts that experienced the highest appreciation during the boom tended to see the steepest declines during the bust. This suggests that price increases in those areas outpaced fundamentals and were subsequently corrected. In contrast, Houston shows considerable persistence: tracts that appreciated more during the boom continued to outperform during the bust. This pattern is consistent with relatively elastic housing supply and more stable, fundamentals-driven price dynamics across neighborhoods.

Figure 2 displays the share weights used to aggregate census tracts into city-level indexes for the two sample cities. These weights—based on the number of housing units, number of rooms, or total housing value—are derived from various Decennial Census American Community Survey datasets.[2] For both Boston and Houston, the spatial distributions of unit and room shares, shown in panels (a) and (b), are broadly similar, suggesting that appreciation rates weighted by these measures are likely to yield comparable results. In contrast, the value-based weights in panel (c) exhibit a markedly different spatial pattern, indicating that indexes based on value weighting may diverge substantially from those based on physical

[2] 1990, 2000, and 2020 tract definitions are converted to 2010 definitions using crosswalk files available from the National Historical Geographic Information System at `https://www.nhgis.org/geographic-crosswalks`. For inter-census years, straight-line imputation is used for imputation.

housing characteristics.

Figure 3 presents estimates of annual and cumulative house price changes under the three alternative weighting schemes. An equally weighted index—constructed by averaging appreciation rates across tracts without regard to housing characteristics or value—is included for comparison.

Panels (a) and (c) show that annual appreciation rates appear remarkably similar across weighting methods. However this similarity does not hold for cumulative changes shown in panels (b) and (d): even small differences in annual rates relative to uniform weights compound over time when patterns are persistent. Consistent with expectations, there is substantial persistence, reflecting ongoing changes in the characteristics of the housing stock.

The cumulative rate of appreciation varies considerably depending on the choice of weighting scheme. Relative equal weighting or weighting by number of units, indexes weighted by rooms per tract tend to show lower cumulative appreciation. This suggests that, in both Boston and Houston, larger housing units—which are typically newer—appreciated at a slower rate over the sample period. The value-weighted indexes exhibit greater volatility over time and diverge more sharply across cities, reflecting the influence of spatial variation in price levels.

Overall, these results highlight the challenges of constructing long-term house price indexes using repeat sales data in cities with pronounced spatial heterogeneity. Differences in appreciation rates across locations are consequential depending on the choice of weighting scheme. If the objective is to measure the cost of housing space, failing to use weights that account for unit size is likely to produce misleading estimates.

7 Conclusions

Precise measurement of housing price changes, including both rental and asset prices, is critical for a wide range of research and practical applications. Over time, numerous refine-

ments to commonly used hedonic and repeat sales index methods have been proposed. This research advances that effort by incorporating intra-city location and unit characteristics, which, according to both economic theory and empirical evidence, are systematically related to housing price.

Previous studies have shown that price changes are not uniform within cities. In particular, shifts in commuting cost—especially those associated with changes in gasoline prices or the introduction of new transportation infrastructure—have been shown to generate non-uniform appreciation patterns. This is the first paper to explore how basic urban economic theory can inform the construction of city-level housing price indexes. The results are that there are theoretical reasons, in addition to the empirical evidence, suggesting that rates of appreciation vary systematically with distance from the city center and that weighting observations by housing units produces different results than considering housing services.

The implications for constructing Laspeyers-type indexes are clear. Given that appreciation rates vary across space, researchers must account for the spatial distribution of data used to create a housing price index. Whether that data come from survey responses or transactions, observations should be weighted by the fraction of housing services at each distance from the city center in order for the index to sufficiently characterize the average rate of change for that city.

Conventional repeat sales and hedonic measures of price change are generally not weighted in this fashion. Fortunately, implementing such measures, particularly in repeat sales indexes, is straightforward and may result in meaningful changes to observed growth rates, as we illustrate using data for 25 US cities from the Metropolitan Sample of the American Housing Survey and repeat sales price estimates for Boston and Houston.

References

Alonso, W. (1964). *Location and land use: Toward a general theory of land rent*. Harvard university press.

Ambrose, B. W., Coulson, N. E., and Yoshida, J. (2023). Housing rents and inflation rates. *Journal of Money, Credit and Banking*, 55(4):975–992.

Anenberg, E. and Laufer, S. (2017). A more timely house price index. *Review of Economics and Statistics*, 99(4):722–734.

Baum-Snow, N. and Han, L. (2024). The microgeography of housing supply. *Journal of Political Economy*, 132(6):1897–1946.

Bogin, A., Doerner, W., and Larson, W. (2019a). Local house price dynamics: New indices and stylized facts. *Real Estate Economics*, 47(2):365–398.

Bogin, A. N., Doerner, W. M., and Larson, W. D. (2019b). Local house price paths: accelerations, declines, and recoveries. *The Journal of Real Estate Finance and Economics*, 58(2):201–222.

Brueckner, J. K. (1987). The structure of urban equilibria: A unified treatment of the muth-mills model. In *Handbook of regional and urban economics*, volume 2, pages 821–845. Elsevier.

Contat, J. and Larson, W. D. (2024). A flexible method of housing price index construction using repeat-sales aggregates. *Real Estate Economics*, 52(6):1551–1583.

D'Lima, W., Lopez, L. A., and Pradhan, A. (2022). Covid-19 and housing market effects: Evidence from us shutdown orders. *Real Estate Economics*, 50(2):303–339.

Edlund, L., Machado, C., and Sviatschi, M. (2022). Gentrification and the rising returns to skill. *Economica*, 89(354):258–292.

Fischer, M. M., Huber, F., Pfarrhofer, M., and Staufer-Steinnocher, P. (2021). The dynamic impact of monetary policy on regional housing prices in the united states. *Real Estate Economics*, 49(4):1039–1068.

Glaeser, E. L., Gottlieb, J. D., and Tobio, K. (2012). Housing booms and city centers. *American Economic Review*, 102(3):127–133.

Larson, W. D. and Zhao, W. (2020). Oil prices and urban housing demand. *Real Estate Economics*, 48(3):808–849.

Laspeyres, E. (1871). Die berechnung einer mittleren waarenpreissteigerung. *Jahrbücher für Nationalökonomie und Statistik*.

Liu, S. and Su, Y. (2021). The impact of the covid-19 pandemic on the demand for density: Evidence from the us housing market. *Economics letters*, 207:110010.

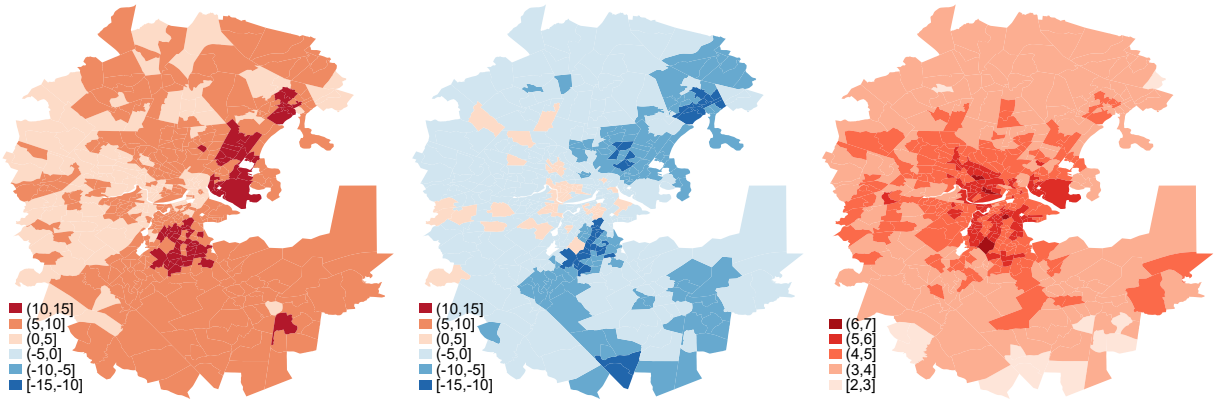
Malone, T. and Redfearn, C. L. (2018). Shocks & ossification: The durable hierarchy of neighborhoods in us metropolitan areas from 1970 to 2010. *Regional Science and Urban Economics*, 69:94–121.

Mills, E. S. (1967). An aggregative model of resource allocation in a metropolitan area. *The American Economic Review*, 57(2):197–210.

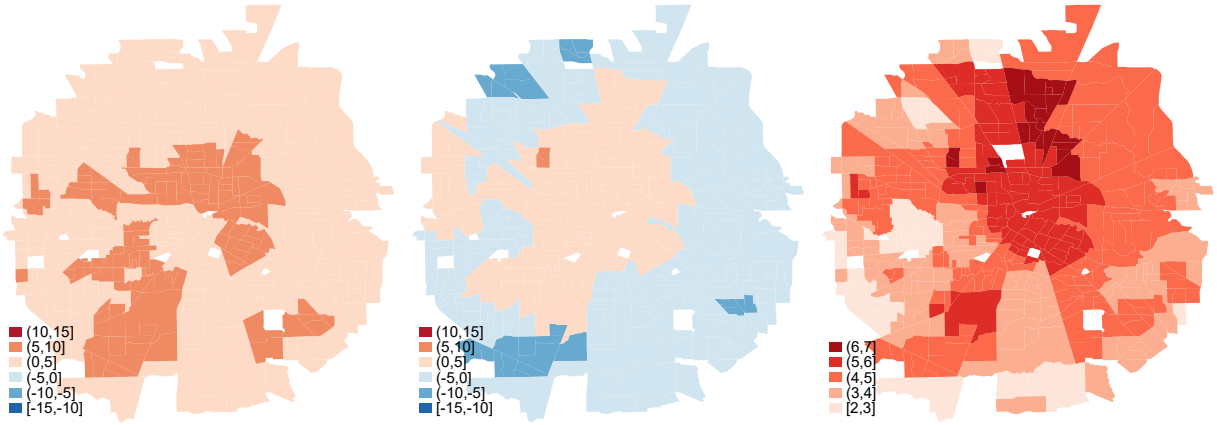
Molloy, R. and Shan, H. (2013). The effect of gasoline prices on household location. *Review of Economics and Statistics*, 95(4):1212–1221.

Muth, R. F. (1969). *Cities and housing: The spatial pattern of urban residential land use.* University of Chicago Press.

Figure 1: Within-city appreciation differences (annual average)



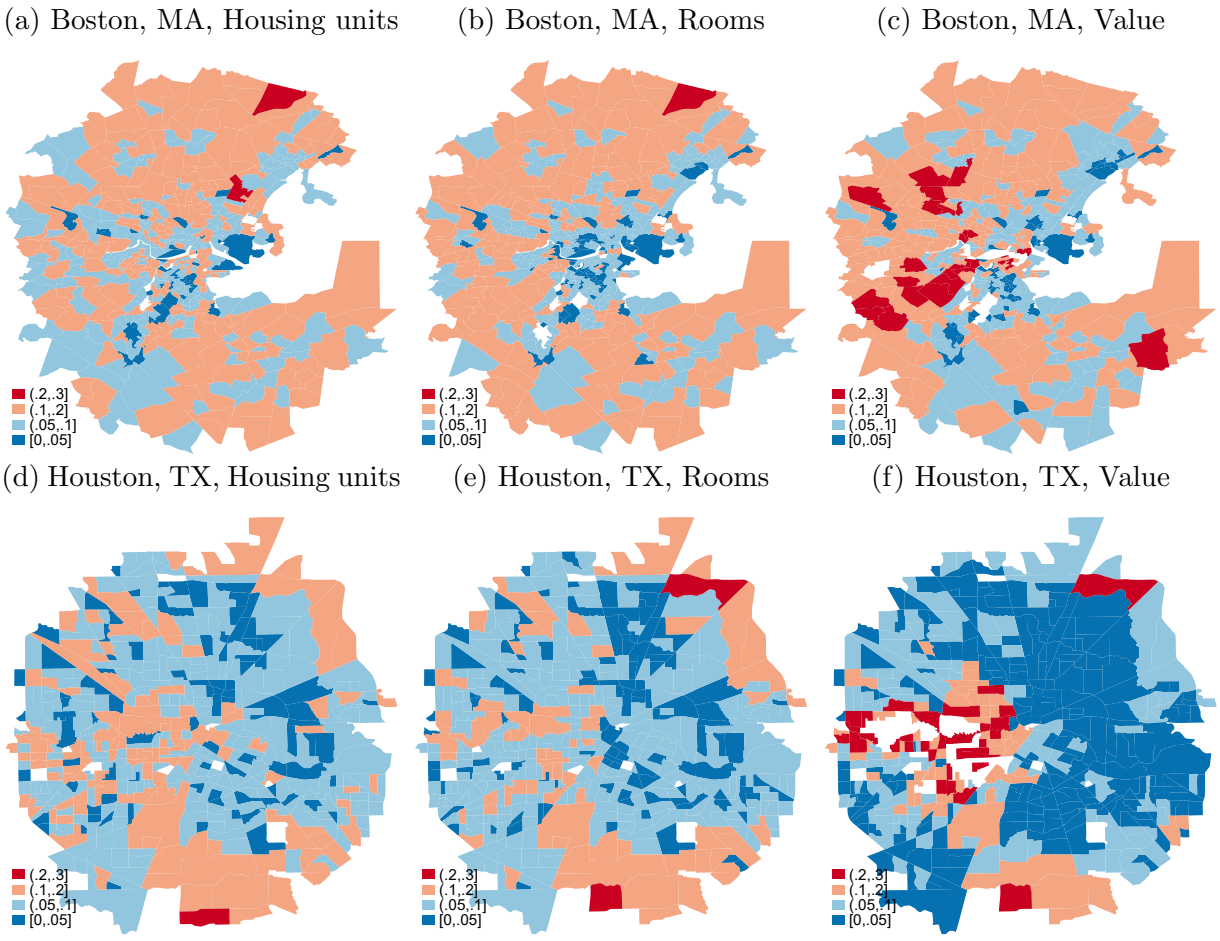
(a) Boston, MA, 2001–2006 (b) Boston, MA, 2006–2011 (c) Boston, MA, 1990–2020



(d) Houston, TX, 2001–2006 (e) Houston, TX, 2006–2011 (f) Houston, TX, 1990–2020

Notes: Maps show the annual geometric average nominal appreciation rate for Census tracts (2010 definitions). Tracts shown have centroids within 15 miles of the centroid of the Census tract containing the respective city's City Hall.
Sources: Contat and Larson (2024); Authors' analysis.

Figure 2: Shares used in city index calculation (2010 values)

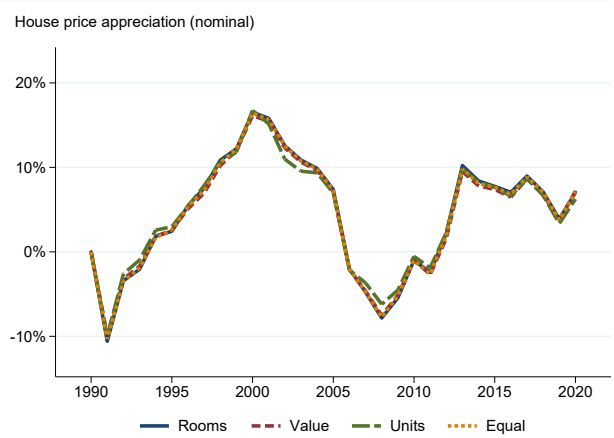


Notes: Maps show the shares used in CBSA-level house price index construction, by Census tract (2010 definitions). Tracts shown have centroids within 15 miles of the centroid of the Census tract containing the respective city's City Hall.

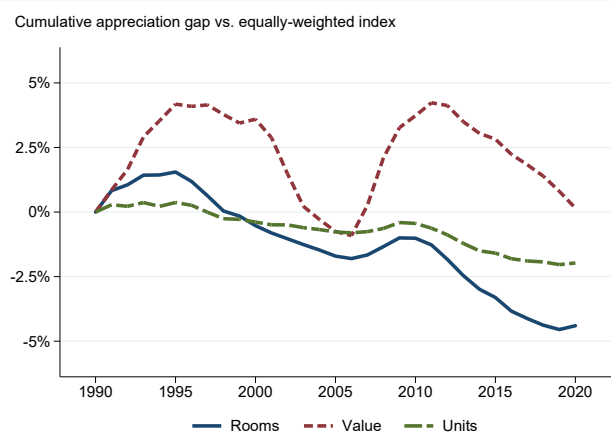
Sources: Census/ACS; Authors' analysis.

Figure 3: Appreciation index differences

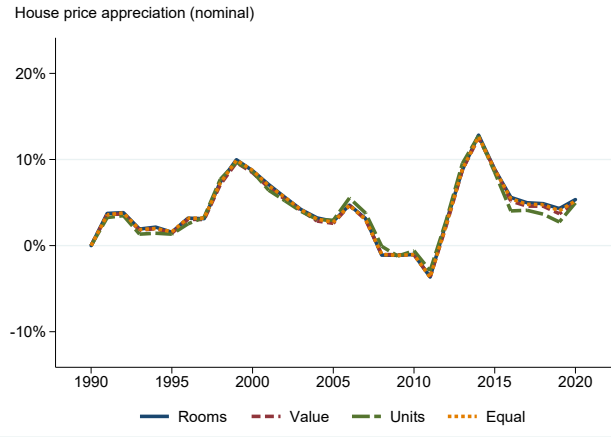
(a) Boston, MA, Annual appreciation



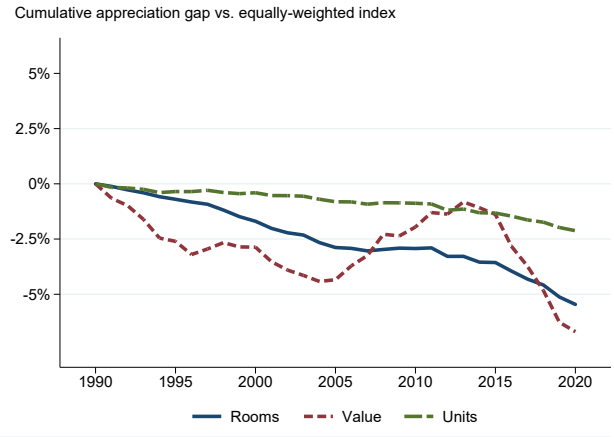
(b) Boston, MA, Cumulative difference



(c) Houston, TX, Annual appreciation



(d) Houston, TX, Cumulative difference



Notes: The figures present alternative city-level house price indices. Each index type (shown in the legend) is constructed by aggregating Census tract (2010 definitions)-level house price appreciation rates using time-varying tract-level weights. The equally-weighted index assigns each tract the same weight.

Sources: Contat and Larson (2024); Census/ACS; Authors' analysis.

Table 1: Compound annual growth rates in median values (2015–2019)

	Metrowide		Central City		Suburbs		Difference	
	Value	Rent	Value	Rent	Value	Rent	Value	Rent
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Atlanta	13.6	5.7	24.5	7.8	11.3	5.7	13.3	2.0
Boston	8.2	6.2	11.7	4.5	8.2	8.8	3.5	-4.3
Chicago	5.7	3.8	9.7	4.1	4.7	3.4	5.1	0.8
Cincinnati	4.7	5.7	7.0	7.5	5.4	8.3	1.6	-0.9
Cleveland	3.2	2.0	0.0	1.8	4.1	6.9	-4.1	-5.1
Dallas	11.0	6.1	10.1	6.1	10.1	6.7	0.0	-0.6
Denver	9.2	7.5	12.5	4.8	10.4	6.2	2.1	-1.4
Detroit	7.5	2.7	10.7	3.5	7.0	2.7	3.6	0.7
Houston	9.3	3.9	9.5	4.3	8.1	5.1	1.4	-0.8
Kansas City	6.2	3.4	5.6	3.4	5.2	2.7	0.3	0.7
Los Angeles	5.5	6.7	6.2	7.4	6.8	6.2	-0.6	1.2
Memphis	9.2	3.9	5.1	3.9	6.8	3.6	-1.7	0.3
Miami	6.9	4.5	8.8	5.6	7.5	4.3	1.3	1.3
Milwaukee	5.0	2.7	5.1	1.9	6.1	5.4	-1.0	-3.6
New Orleans	4.1	1.6	5.6	1.6	5.7	3.2	-0.1	-1.6
New York City	4.3	4.1	4.7	3.8	4.0	4.5	0.6	-0.7
Philadelphia	5.3	4.1	7.5	5.6	4.7	4.2	2.9	1.4
Phoenix	11.1	7.0	11.5	7.5	10.7	4.6	0.8	3.0
Pittsburgh	5.3	2.0	13.6	7.7	5.1	2.1	8.5	5.6
Portland	9.4	7.9	9.8	10.1	9.3	7.5	0.5	2.6
Raleigh	4.7	4.9	1.5	9.3	8.0	6.1	-6.5	3.2
Riverside	6.8	6.8	7.5	8.7	6.6	5.7	0.8	3.0
San Francisco	8.7	6.6	9.3	7.0	9.5	8.5	-0.2	-1.5
Seattle	10.7	7.2	13.6	6.8	10.0	7.4	3.7	-0.6
Washington DC	1.4	2.7	1.0	1.6	2.7	2.7	-1.6	-1.1
Average	7.1	4.8	8.5	5.5	7.1	5.3	1.4	0.1
Deviation	2.8	1.9	4.9	2.4	2.3	1.9	3.8	2.4

Values in percents. Authors' calculations using reported median values from the American Housing Survey Metropolitan Sample. Approximately 2,000 housing units are interviewed for each metro area. Differences in growth rates are calculated as central city minus suburbs.

Table 2: Compound annual growth rates in median values (2015–2019)

	Simple Avg		Laspeyres		Difference	
	Value	Rent	Value	Rent	Value	Rent
	[1]	[2]	[3]	[4]	[5]	[6]
Atlanta	17.91	6.75	12.96	5.99	-4.95	-0.75
Boston	9.92	6.64	9.03	7.72	-0.89	1.09
Chicago	7.20	3.77	6.65	3.69	-0.55	-0.08
Cincinnati	6.20	7.90	5.69	8.18	-0.51	0.28
Cleveland	2.03	4.32	3.05	5.60	1.02	1.28
Dallas	10.13	6.37	10.13	6.36	0.00	-0.01
Denver	11.41	5.53	11.23	5.65	-0.18	0.12
Detroit	8.85	3.10	8.25	2.98	-0.60	-0.12
Houston	8.83	4.74	8.71	4.82	-0.13	0.07
Kansas City	5.40	3.07	5.37	3.01	-0.03	-0.06
Los Angeles	6.50	6.77	6.46	6.85	-0.04	0.08
Memphis	5.99	3.79	5.97	3.79	-0.02	0.00
Miami	8.12	4.93	7.78	4.59	-0.34	-0.34
Milwaukee	5.58	3.65	5.62	3.80	0.04	0.15
New Orleans	5.67	2.40	5.67	2.41	0.00	0.00
New York City	4.35	4.13	4.32	4.16	-0.03	0.03
Philadelphia	6.09	4.86	5.45	4.54	-0.64	-0.31
Phoenix	11.11	6.05	11.19	6.37	0.08	0.32
Pittsburgh	9.38	4.92	6.29	2.87	-3.09	-2.05
Portland	9.57	8.81	9.54	8.64	-0.03	-0.17
Raleigh	4.73	7.71	4.88	7.64	0.15	-0.07
Riverside	7.05	7.24	6.87	6.61	-0.17	-0.63
San Francisco	9.44	7.78	9.43	7.72	-0.01	-0.06
Seattle	11.79	7.10	11.46	7.16	-0.33	0.06
Washington DC	1.85	2.14	2.24	2.40	0.40	0.25
Average	7.80	5.38	7.37	5.34	-0.43	-0.04
Deviation	3.30	1.80	2.70	1.90	1.15	0.58

Values in percents. The simple average index is the mean of the central city and suburbs growth rates from Table 1. The Laspeyres index weights the growth rates by the total number of units, renter and owner, in each location. Differences between the indexes are calculated as Laspeyres minus simple average.