Shifting House Price Gradients: Evidence Using Both Rental and Asset Prices

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Abstract

Alonso (1964), Mills (1967) and Muth (1969) formalize the monocentric urban spatial structure model and provide the gradient approach to analyze the issue of suburbanization. Urban sprawl has been observed and studied since then. However, recent evidence suggests a reversal: center cities are gaining population. This literature has been based on changes in population density or the slope of the housing asset price gradient. This paper adds to this research by estimating the changing slope of both the rental and asset price gradients for a wide metropolitan areas in the U.S. over a 30 year period. The steepening of the asset and rental gradients is then analyzed at disaggregate geographic levels, showing that regions have not all followed the national trend. For the owner-occupied market, asset price gradient has been steepening in all regions but the Midwest. Whereas in the rental market, all regions but the Northeast experienced comparable increases in the slope of the rent gradient. The house price gradient, whether measured using asset or rental prices, increased in slope fastest in big cities with high GDP and large population. Possible reasons for the steepening of house price gradient are then developed using the standard urban model (SUM). The Muth-Mills equation predicts that the slope of house price gradient should vary directly with congestion in urban travel and inversely with housing unit size. The empirical tests evidenced in this paper are performed using a specially constructed panel data set of U.S. metropolitan areas and confirmed these expected relations.

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1. Introduction

Alonso (1964), Mills (1967) and Muth (1969) formalize the monocentric urban spatial structure model and provide the gradient approach to analyze the issue of suburbanization. In a monocentric city, all employment is located in CBD. Identical households make the choice of residence location by optimizing between the cost of commuting to the CBD and housing expenditure. Households living farther away from the CBD and bearing higher commuting costs are compensated by lower housing prices and larger housing consumption. Brueckner (1987) presents a unified treatment of the Muth-Mills model and shows that the price per square foot of housing p drops with distance x to CBD and that this rate is a function of commuting cost per round-trip mile t and household consumption of housing q, which is affected by some exogenous factors α.

$$\frac{\partial p}{\partial x} = -\frac{t}{q(x;\alpha)} \tag{1}$$

Urban sprawl has been observed and studied since then. Mills (1972), Mieszkowski et. al. (1993), Glaeser and Kahn (2004) and many others have used estimates of the changing population density gradient to measure the American suburbanization. Various causes have been related to sprawl, including unpriced traffic congestion (Anas and Rhee, 2006), availability of roads and highways (Anas and Pines, 2008), low crime rate and quiet neighborhoods in the suburbs (Couch and Karecha, 2006), change of age and household structure (Jaeger and Schwick, 2014), and the improvement of economic base (Brueckner and Helsley 2011). The issue is whether urban expansion is "purely in response to fundamental forces" or due to some market failures that "may distort their operation … and justifying criticism of urban sprawl" (Brueckner 2000).

Recent evidence suggests a reversal: center cities are gaining population and studies. Recent studies have started to focus on the revival of the city. There is evidence suggesting that center city is becoming more expensive and popular among the highly educated younger generations. Almost all large American cities have experienced large increases in young professionals near CBD since 2000 (Couture and Handbury 2016), and millennials as the creative class prefer living in center cities (Florida 2002). Great divergence of jobs, income, retail services and amenities start to emerge in big cities (Moretti 2012, Diamond 2016). Edlund et al. (2016) argues that gentrification is a result of longer working hours of households as workers favor the proximity to work and city amenities more than large housing space. Glaeser, Gottlieb, and Toibo (2012) found that, within metropolitan areas, median house value grew faster in neighborhoods closer to the center city. Bogin et. al. (2018) finds larger house price appreciation in areas closer to the city center within large cities. Their work is the first evidence documenting the steepening of within-city house price gradient.

The literature on city spatial structure change was initially based on changes in the population density gradient and most recently has switched to the slope of the housing asset price gradient. The rental price gradient has been ignored although most center city housing is rental in the largest cities. This paper adds to this research by providing direct evidence documenting the shift of the housing price gradient using both the asset price of the owner-occupied market and the rental price of the rental market for a wide range of metropolitan areas in the U.S. over a 30 year period. Comparing the relative asset and rental price changes between the center city and the suburbs within metropolitan areas, tests are conducted on metropolitan areas that are disaggregated by region, GDP or population. Thus, this paper extends the literature by presenting the results on the city spatial structure change from the perspective of both the owner-occupied market and the rental market on various disaggregated geographic levels.

Studying the shift of house price gradient requires the construction of house price indices. Commonly used asset price indices are Case-Shiller index and FHFA index, which are both based on the repeated sales methodology and are highly correlated. However, repeated sales price index often cannot fully differentiate the observed market price changes from changes in housing quality characteristics. Also, repeat sales method may suffer from sample selection bias, since homes with repeat sales may be fundamentally different from those with single sales and rising prices may induce housing improvements. Another commonly used method of constructing house price index is hedonic estimation, and various researchers used hedonic house price index to investigate house prices and housing characteristics relationship (Meese and Wallace 1997, Dunse and Jones 1998, and Wilhelmsson 2000). However, this method is vulnerable to omitted variable bias and ignorance of function form.

This paper provides direct evidence documenting the reversal of falling house price gradients over a wide range of metropolitan areas over a long time period. Using American Housing Survey (AHS), measures of "center city vs. suburb" house price ratio are constructed along with measures of appreciation rates differentials for the owner-occupied and rental units respectively. Because this is panel data, it is relatively easy to control for the quality characteristics of housing units. The comprehensive information contained in AHS facilitates construction of a panel of house price, average appreciation and appreciation rate in both the owner-occupied and rental market for nearly 100 MSAs during 1985-2013. The changes of house price ratio and appreciation differential between the center city and the suburbs reflect the shift of house price gradient over time.

Three main stylized facts are found. First, both asset and rental prices increased at a faster rate in the center city than in the suburbs, implying steepening of house price gradients in both markets over the sample period. Second, regions have not all followed the same general trend. For the owner-occupied market, asset price in center city stayed stable relative to suburbs in the Midwest, but grew relative to the suburbs in other regions. Whereas in the rental market, all regions experienced comparable increases in the steepness of the rent gradient except in the Northeast. Third, the house price gradient, whether measured using asset or rental prices, increased in slope fastest in big cities with high income per capita and large population.

The theoretical reasons for the steepening of house price gradient are then developed using the standard urban model (SUM). Muth-Mills equation illustrates that the rate at which house price falls with distance to CBD is related positively with transportation cost but negatively with the demand for housing at that location. Empirical tests evidenced in this paper uses a specially constructed panel data set of U.S. metropolitan areas and confirm these expected relations. Tests of house price ratios and appreciation rate differentials for both asset and rental prices between the center city and the suburbs are conducted on congestion and city income. The results for the owner-occupied market are consistent with the prediction of Muth-Mills equation.

The reminder of the essay proceeds as follows. The next section outlines how the house price ratio and appreciation rate differential are constructed in a bottom-up way and compares them to existing housing price indices. Section three discusses the stylized facts from the indices of the house price gradients, which is followed by empirical tests on how the standard urban model (SUM) can explain the steepening of house price gradients. The final section concludes with a summary and implications.

2. House Price Gradient Indices Construction

The American Housing Survey (AHS) is a panel data set in which the same housing units are revisited every other year. It provides detailed property-level information, including price (asset price of owner-occupied homes, and the rental price of renter-occupied units), housing quality characteristics, center city/suburb status, tenure status as well as metropolitan area variables. Because this is panel data, it is relatively easy to control for the quality characteristics of housing units and to avoid the sample selection bias of repeated sales method and the omitted variable bias of the hedonic estimation method. Publicly available AHS files are used to construct a panel data of house prices and appreciation rates for owner-occupied and rental markets, covering more than 100 metropolitan areas over 1985-2013.

In general, the method used to measure the house price gradients is bottom-up. For each sampled housing unit i in MSA c in year y, AHS contains information of its house price of the entire unit $P_{i,c,y}$ (which is house asset value for owner-occupied unit and rental price for rental unit, and is deflated using 1985 as base year when it's used to calculate other variables), its interior space in square foot $S_{i,c,y}$ and some key quality characteristics, such as the age of building, number of bedrooms and bathrooms, structure type, whether it was renovated in the survey year or the year before, etc.. The interior space $S_{i,c,y}$ is constant for one housing unit, because the housing unit is treated as a new one if its interior space or one of the key quality characteristics changed in a survey year. Thus, the inflation-adjusted house price per square foot $p_{i,c,y}$, average annual appreciation rate of the unit house price $R_{i,c,y}$, and the appreciation rate of house price per square foot $r_{i,c,y}$ can be calculated for each housing quality-controlled unit in the owner-occupied market and rental market.

$$p_{i,c,y} = \frac{P_{i,c,y}}{S_{i,c,y}} \tag{2}$$

$$R_{i,c,y} = \frac{1}{2} ln(\frac{P_{i,c,y}}{P_{i,c,y-2}}) \tag{3}$$

$$r_{i,c,y} = \frac{1}{2} ln(\frac{p_{i,c,y}}{p_{i,c,y-2}}) \tag{4}$$

The housing market of MSA c in year y is divided into four segments based on the tenure status $T = own,\ rent$ (owner-occupied or rental) and the metropolitan status $M = CC,\ S$ (center city or suburbs). For each tenure-metro segment of the housing market, the average house price $P_{T,M,c,y}$ (asset or rental price depending on the tenure status), average house price per square foot $p_{T,M,c,y}$, average annual appreciation rate of house price $R_{T,M,c,y}$ and average annual appreciation rate of house price per square foot $r_{T,M,c,y}$ can be generated as the (weighted) average of these values of housing units in the tenure-metro segment in MSA c in year y. The survey weights contained in AHS data set matches the national sample better. For robustness purposes, both the weighted average and unweighted simple average methods are tested to construct the panel of MSA-level house prices and appreciation rates for both owner-occupied and rental markets, and the results are consistent. In the following sections, the simple average MSA-level house prices and appreciation rates is used to generate the house price gradient indices and to conduct empirical tests framed by Muth-Mills equation.

$$house\ price:\ P_{T,M,c,y} = \frac{1}{N} \sum_{i=1}^{N} P_{i,T,M,c,y} \tag{5}$$

$$house\ price\ per\ square\ foot:\ p_{T,M,c,y} = \frac{1}{N} \sum_{i=1}^{N} p_{i,T,M,c,y} \tag{6}$$

$$house\ price\ appreciation\ rate: \ R_{T,M,c,y} = \frac{1}{N}\sum_{i=1}^{N} R_{i,T,M,c,y} \tag{7}$$

$$appreciation\ rate\ of\ house\ price\ per\ square\ foot: \ r_{T,M,c,y} = \frac{1}{N}\sum_{i=1}^{N} r_{i,T,M,c,y} \tag{8}$$

The slope of the house price gradients of each metropolitan area are generated as the price ratios and appreciation rate differentials between its center city and the suburbs, using asset prices and rental prices for owner-occupied and rental market respectively. This paper tests on the change of the slope of house price gradients over time following the framework of SUM, instead of trying to calculate the house price at every location in the city and tracing out the entire house price gradient for each of the years in my sample period. According to Muth-Mills equation, changes in the house price ratio between center city and suburb indicate the shift of house price gradients, so the price ratio is a function of congestion cost t, housing space q, as well as some other exogenous variables α that affect the household demand for housing. The appreciation rate differential between center city and suburb can be used as an indicator of the shift of the house price gradients. The house price appreciation rate differential is a function of change of transportation cost, change of housing space, and exogenous variables that affect the household demand for housing.

$house\ price\ ratio\ between\ center\ city\ and\ suburbs:$

$$HPR_{T,c,y} = \frac{P_{T,CC,c,y}}{P_{T,S,c,y}} = f(t, q; \alpha) \tag{9}$$

$ratio\ of\ house\ price\ per\ sqft\ between\ center\ city\ and\ suburbs:$

$$SQFTHPR_{T,c,y} = \frac{p_{T,CC,c,y}}{p_{T,S,c,y}} = f(t, q; \alpha) \tag{10}$$

Besides generating average house prices and appreciation rates to construct a panel of

MSA-level house price gradient indices, this paper also constructs panels of house price ratios and appreciation rate differentials between center city and suburbs on national and regional levels for both owner-occupied and rental markets. The most commonly used house price indices in the literature are FHFA house price index and Case-Shiller. Both are repeated sales indices that cover only selected owner-occupied housing market. The national level average asset prices in the center city and in the suburbs, $P_{own,CC,US,y}$ and $P_{own,S,US,y}$, generated using AHS data and the method described above can comparable to FHFA HPI and Case-Shiller index, as they all measure the aggregate owner-occupied market, despite of the different sample coverage.

Figure 1 and Table 2 illustrate the comparison among national average asset prices from AHS, Case-Shiller index and FHFA house price index. All indices are normalized by setting values in year 2013 as 100, including: (1) national average asset price from AHS, (2) national average asset price in center city from AHS, (3) national average asset price in suburbs from AHS, (4) national average asset price per square foot from AHS, (5) national average asset price per square foot in center city from AHS, (6) national average asset price per square foot in suburbs from AHS, (7) FHFA HPI, and (8) Case-Shiller index. Average Asset prices generated from AHS have similar time trend to Case-Shiller index and FHFA house price index except during 1990s. All indices are highly correlated as shown in Figure 2.

3. Stylized Facts

This paper examines the change in the slope of house price gradients over time following the framework of SUM, instead of finding the house price at every location in the city and tracing out the entire house price gradient for each of the years in the sample period. Changes in the "center city vs. suburb" house price ratios and appreciation rate differentials over time provide direct evidence of the shift of house price gradients in the owner-occupied market and rental market.

On the national level, both asset price and rental price increased at a faster rate in the center city relative to the suburbs. Figure 2 illustrates the national average "center city vs suburb" house price ratio and ratio of house price per square foot in the owner-occupied and rental markets. Both panels show a strong upward trend, suggesting that both asset and rental prices in center city have been rising more compared to its counterpart in the suburbs. Especially for price per square foot of housing, center city is more expensive to live for renters since mid 1990s, and it's more expensive for homeowners since early 2000s. Figure 3 tells the same story in terms of average appreciation rates in center city and the suburbs. Both owner-occupied and rental markets experienced larger price appreciation in 1990s and late 2000s.

To examine if there is a persistent time trend of the change in the slope of house price gradients, tests are conducted using equation (11) and (12). "Center city vs. suburb" house price ratio $HPR_{T,c,y}$ in MSA c in year y on the owner-occupied market $T = own$ is the ratio of asset prices between center city and the suburbs, while that on the rental market $T = rent$ is the ratio of rental prices between the center city and the suburbs. $SQFTHPR_{T,c,y}$ is the ratio of house price per square foot between center city and the suburbs in MSA c in year y. The time trend variable $year$ is coded with the year 1985 as 0, year 1987 as 2, and so on so forth until year 2013 as 28. This is because AHS is conducted every other year. MSA is the metropolitan area fixed effect, and $\varepsilon_{c,y}$ is the error term. The recent evidence of center cities gaining population suggests a positive β and an increase in the slope of both asset price and rental price gradients over time.

$$HPR_{T,c,y} = \alpha + \beta * year_y + MSA + \varepsilon_{c,y} \tag{11}$$

$$SQFTHPR_{T,c,y} = \alpha + \beta * year_y + MSA + \varepsilon_{c,y} \tag{12}$$

Further tests are then conducted when metropolitan areas are grouped by region, GDP or population. The aim of these tests is to explore whether the steepening of the house price gradients is a national housing market phenomenon or a local behavior that is related to the geographic location or the local economy fundamentals of the metropolitan areas. In equation (13) and (14), a region - time trend interaction term is added with the aim of testing the potential geographic differences in the shift of house price gradients. $REGION$ includes the region dummies of West, Midwest and Northeast, using the South as the reference. Equation (15) and (16) intend to examine if the shift of house price gradients over time has been different among metropolitan areas with various GDP levels. Metropolitan areas are grouped into four quartiles based on real GDP per capita in 2013, and GDP includes the group dummies of Low(bottom 25%), Lower-Middle (25%-50%) and Upper-Middle (50%-75%), with the High GDP group (top 25%) as the reference. Similar tests using population ranking are conducted in equation (17) and (18). POP includes the group dummies of Low (bottom 25%), Lower-Middle (25%-50%) and Upper-Middle (50%-75%) when metropolitan areas are ranked based on its population in 2013. The recent literature of city revival and gentrification suggest that urban travel cost together with employment, retail services and amenities at inner cities attract the younger generations to move back into cities.

$Tests\ with\ a\ region - time\ trend\ interaction\ term$:

$$HPR_{T,c,y} = \alpha + \beta * year_y + \gamma * (year * REGION) + MSA + \varepsilon_{c,y} \tag{13}$$

$$SQFTHPR_{T,c,y} = \alpha + \beta * year_y + \gamma * (year * REGION) + MSA + \varepsilon_{c,y} \tag{14}$$

$Tests\ with\ a\ GDP - time\ trend\ interaction\ term:$

$$HPR_{T,c,y} = \alpha + \beta * year_y + \gamma * (year * GDP) + MSA + \varepsilon_{c,y} \tag{15}$$

$$SQFTHPR_{T,c,y} = \alpha + \beta * year_y + \gamma * (year * GDP) + MSA + \varepsilon_{c,y} \tag{16}$$

$Tests\ with\ a\ population - time\ trend\ interaction\ term:$

$$HPR_{T,c,y} = \alpha + \beta * year_y + \gamma * (year * POP) + MSA + \varepsilon_{c,y} \tag{17}$$

$$SQFTHPR_{T,c,y} = \alpha + \beta * year_y + \gamma * (year * POP) + MSA + \varepsilon_{c,y} \tag{18}$$

In Table 2, shown in column (1)-(4) are the test results when the slope of asset price gradient is measured as price ratio, and in column (5)-(8) are those when the slope is measured as ratio of asset price per square foot. These two sets of tests have very similar results. The slope of asset price gradient has been rising by 0.3% annually on average when measured by house price ratio and 0.5% when measured by ratio of house price per square foot. During the sample period of 1985-2013, the asset price gradient becomes steeper across the metropolitan areas in the US. The regional differences are shown in column (2) and (6). Asset price in center city stayed stable relative to that in suburbs in the Midwest, but the center city asset price grew relative to the suburbs in other regions, especially in the South. Results in column (3)-(4) and (7)-(8) provide support to the recent studies on the revival of cities and gentrification. Compared to the suburbs, center cities within big metropolitan areas, whether measured by GDP or population, experience faster asset price growth than those in relatively small metropolitan areas. Metropolitan areas with the highest GDP and population experienced the strongest steepening of asset price gradient, with an average annual growth of 0.5%-0.9% in the slope of asset price gradient, depending on whether it's measured as price ratio or ratio of price per square foot.

Results on the rental market are shown in Table 3. Similarly, column (1)-(4) are the results on rental price ratio, and column (5)-(8) are those on ratio of rental price per square foot. The slope of rental price gradient - when measured as the rental price ratio between center city and the suburbs - has been rising at 0.5% annually on average over the sample period, which is comparable to the rate of shift of asset price gradient. All regions experienced comparable increase in the slope of rental price gradient, expect for the Northeast in where the ratio of rental price between center city and suburbs has stayed relatively stable. Similar to the owner-occupied market, the rental market in big metropolitan areas, in terms of GDP and population, has the strongest steepening of rental price gradient, as shown in column (3) and (4).

These results add to the literature by providing direct evidence on the shift of rental price gradient, as existing studies focus on the city spatial structure change in owner-occupied market only. Also, these tests demonstrate that the steepening of rental price gradient and that of asset price gradient -- when measured as center city vs. suburb ratio of prices of the entire housing units-- are comparable in terms of the average annual growth rate of the slopes and its correlation with region, GDP and population. It provides support for the academic research on causes of gentrification and urban revival from the rental market perspective. However, the ratio of rental price per square foot is not rising, as shown in column (5)-(8), which leaves a puzzle regarding the relation between housing space change and price change in the rental market.

As the growth rates in the slopes of asset and rental price gradients are comparable in the owner-occupied and rental market, it suggests that the capitalization rate in center city CAP_{CC} and that in the suburbs CAP_S have similar changes over time, according to the dividend pricing hypothesis. If it is true, the ratio of capitalization rates between center city and the suburbs should have no time trend.

$$\frac{HPR_{own,c,y}}{HPR_{own,c,y-1}} = \frac{HPR_{rent,c,y}}{HPR_{rent,c,y-1}} \quad (19)$$

$$\Leftrightarrow \frac{P_{own,CC,c,y} / P_{own,S,c,y}}{P_{own,CC,c,y-1} / P_{own,S,c,y-1}} = \frac{P_{rent,CC,c,y} / P_{rent,S,c,y}}{P_{rent,CC,c,y-1} / P_{rent,S,c,y-1}} \quad (20)$$

$$\Leftrightarrow \frac{P_{rent,S,c,y} / P_{own,S,c,y}}{P_{rent,S,c,y-1} / P_{own,S,c,y-1}} = \frac{P_{rent,CC,c,y} / P_{rent,CC,c,y}}{P_{rent,CC,c,y-1} / P_{rent,CC,c,y-1}} \quad (21)$$

$$\Leftrightarrow \frac{CAP_{S,c,y}}{CAP_{S,c,y-1}} = \frac{CAP_{CC,c,y}}{CAP_{CC,c,y-1}} \quad (22)$$

$$\Leftrightarrow \frac{CAP_{S,c,y}}{CAP_{CC,c,y}} = \frac{CAP_{S,c,y-1}}{CAP_{CC,c,y-1}} \quad (23)$$

Capitalization rates in center city and in the suburbs on MSA level are constructed using the pooled tenure hedonic estimation method following Phillips (1988). $log(P_{i,y,c,M})$ is the log of market value for owner-occupied unit i in year y in MSA c with metro status $M = CC \text{ or } S$, or the log of annual rent for rental unit i in year y in MSA c with metro status $M = CC \text{ or } S$. $OWN_{i.y,c,M}$ is a dummy variable indicating if housing unit i is owner-occupied in year y MSA c with metro status $M = CC \text{ or } S$. $X_{i,y,c,M}$ is a vector of housing quality characteristics, including structure type of the building, age of the unit and its square, unit size in square feet, number of bedrooms, number of bathrooms, number of half bathrooms, garage dummy, basement dummy, type of air system, type of heating system, and housing adequacy score.

Regression are estimated for each state and each year separately to generate a panel of different β estimates by state and by year. The β parameter estimates the average percentage difference in $log(P_{i,y,c,M})$ between owner-occupied units and rental units, controlling for differences in specified housing quality characteristics. Then the capitalization rate can be calculated as the antilog of β.

$$log(P_{i,y,c,M}) = \alpha_{i,y,c,M} + \beta * OWN_{i.y,c,M} + X_{i,y,c,M}\gamma' + \varepsilon_{i,y,c,M} \quad (24)$$

$$CAP_{y,c,M} = Rental\ Price\ /\ Asset\ Price = exp(-\beta_{y,c,M}) \tag{25}$$

Equation (26)-(29) shows the test on the time trend of the capitalization rate ratio between center city and the suburbs. $\frac{CAP_{S,c,y}}{CAP_{CC,c,y}}$ is the ratio of the capitalization rates between suburbs and center city in metropolitan area c in year y. The time trend variable $year$ is coded in the same method as in equations (11)-(18). The rest of the equation includes a constant σ, MSA fixed effects MSA, and an error term $\xi_{c,y}$. Results are shown in Table 4. As predicted by previous regressions, ρ is not significant in the models, suggesting that there is no time trend of the CAP ratios between center city and the suburb over the sample period.

$$\frac{CAP_{S,c,y}}{CAP_{CC,c,y}} = \sigma + \rho * year_y + MSA + \xi_{c,y} \tag{26}$$

$$\frac{CAP_{S,c,y}}{CAP_{CC,c,y}} = \sigma + \rho * year_y + \varphi * (year * REGION) + MSA + \xi_{c,y} \tag{27}$$

$$\frac{CAP_{S,c,y}}{CAP_{CC,c,y}} = \sigma + \rho * year_y + \varphi * (year * GDP) + MSA + \xi_{c,y} \tag{28}$$

$$\frac{CAP_{S,c,y}}{CAP_{CC,c,y}} = \sigma + \rho * year_y + \varphi * (year * POP) + MSA + \xi_{c,y} \tag{29}$$

To sum up, three main stylized facts are found. First, both asset and rental prices increased at a faster rate in the center city relative to suburbs, suggesting the steepening of house price gradients in both markets over the sample period. Second, regions have not all followed the general trend. For the owner-occupied market, asset price in center city stayed stable relative to suburbs in the Midwest, but grew relative to the suburbs in other regions. Whereas in the rental market, all regions experienced comparable increases in the steepness of the rent gradient except in the Northeast. Third, the house price gradient, whether measured using asset or rental prices, increased in slope fastest in cities with high GDP and large population.

4. Causes of the shift of house price gradient

Possible reasons for the steepening of house price gradients are developed using the standard urban model (SUM). The Muth-Mills equation predicts that the slope of house price gradient should vary directly with congestion in urban travel and inversely with housing unit size. Urban Mobility Scoreboard constructed by Texas A&M Transportation Institute is used to generate a panel of congestion cost as well as the congestion delay in hours on metropolitan area level for over 1985-2013. Interior housing space is endogenous as it depends on the house prices. Instead, city income is tested using MSA-level inflation-adjusted per capita personal income computed by the Bureau of Economic Analysis (BEA).

The empirical tests are based on equations (30)-(37). $congestion_{c.y}$ is the congestion cost in MSA c in year y, and there are four alternative measures using data from Urban Mobility Scoreboard, depending on the model -- total congestion delay in billion hours, per commuter congestion delay in thousand hours, total congestion cost in billion dollars, and per commuter congestion cost in thousand dollars. $income_{c,y}$ is per capita personal income in MSA c in year y. All other variables are the same as previously defined in equation (11)-(18).

$$HPR_{T,c,y} = \alpha + \theta * congestion_{c.y} + \delta * income_{c,y} + \beta * year_y + MSA + \varepsilon_{c,y} \quad (30)$$

$$SQFTHPR_{T,c,y} = \alpha + \theta * congestion_{c.y} + \delta * income_{c,y} + \beta * year_y + MSA + \varepsilon_{c,y} \quad (31)$$

$$HPR_{T,c,y} = \alpha + \theta * congestion_{c.y} + \delta * income_{c,y} + \beta * year_y + \gamma * (year * REGION) + MSA + \varepsilon_{c,y} \quad (32)$$

$$SQFTHPR_{T,c,y} = \alpha + \theta * congestion_{c.y} + \delta * income_{c,y} + \beta * year_y + \gamma * (year * REGION) + MSA + \varepsilon_{c,y} \quad (33)$$

$$HPR_{T,c,y} = \alpha + \theta * congestion_{c,y} + \delta * income_{c,y} + \beta * year_y + \gamma * (year * GDP) + MSA + \varepsilon_{c,y}$$

(34)

$$SQFTHPR_{T,c,y} = \alpha + \theta * congestion_{c,y} + \delta * income_{c,y} + \beta * year_y + \gamma * (year * GDP) + MSA + \varepsilon_{c,y}$$

(35)

If the shift of house price gradients can be explained by congestion cost and housing space as predicted by SUM, then the time trend will not be significant in these results. According to Muth-Mills equation, θ is expected to be negative, as worse congestion makes the proximity to work more preferable. However, the sign of δ is ambiguous. A rise in city income may cause a decrease in the slope of house price gradient as the household demand for housing space varies directly with income. Whereas, higher income is also associated with higher time cost of commuting, thus driving up the slope of house price gradient. For owner-occupied market, results of tests using equations (30) are reported in column (1)-(4) in Table 5, and those using equations (31) are reported in column (5)-(8) in Table 5. For rental market, results of tests using equations (30) are reported in column (1)-(4) in Table 6, and those using equations (31) are reported in column (5)-(8) in Table 6.

For the owner-occupied market, house price gradient varies directly with congestion -- whether it is measured in delay hours or congestion cost. This finding confirms the prediction of Muth-Mills equation. When asset price gradient is measured by asset price ratio, its slope rises by 0.9 (37%-41% steeper than "no delay" situation) if total annual congestion delay extends by 1 billion hours or by 0.06 if total annual congestion cost increases by 1 billion dollars. When asset price gradient is measured by ratio of asset price per square foot, 1 billion more hours of total annual congestion delay is association with an increase in its slope by 1.7 (18%-23% steeper than “no delay” situation), and 1 billion more dollars of total annual congestion cost pushes up the slope by 0.1. Per commuter congestion delay hours and cost are also statistically significant when asset price per square foot is used. However, the shift of asset price gradient is not significantly correlated with city income. Considering the off-setting effect of rising income on household’s increasing demand for housing space and higher time cost of commuting, this result is not surprising. Last but not least, the time trend of changes in the slope of asset price gradient found in previous tests disappears, as shown in Table 5. It suggests that congestion is the major factor, and that SUM can well explain the empirically observed steepening of asset price gradient over time. The rising trend in asset price ratio is entirely due to the changing transportation conditions, not to the changes in millennials’ different housing preferences as is commonly believed.

For the rental market, no significant correlation between rental price gradient steepening and changing transportation conditions nor city income can be found in these tests. This suggests that the rising trend in rental price ratio is not due to congestion, which leaves a puzzle regarding the relation between the standard urban model and the movement of the rental price gradient.

Regressions results of equation (32) and (33) for owner-occupied market and rental market are reported in Table 7 and Table 8 respectively. And Table 9 and Table 10 demonstrate the results of equation (34) and (35) for owner-occupied and rental markets. Similarly to the baseline tests shown in Table 5, Table 7 and Table 9 suggest that congestion explains the steepening of asset price gradient very well but city income fails to do so. Also, the effect of time trend on the shift of asset price gradient is insignificant in all models. Table 8 and Table 10 illustrate similar results to the baseline regressions in Table 6 as well. The shift of rental price gradient cannot be statistically explained by congestion and city income, even when regional or GDP interactive terms are added.

5. Conclusion and Implication

Alonso (1964), Mills (1967) and Muth (1969) formalize the monocentric urban spatial structure model and provide the gradient approach to analyze the issue of suburbanization. Urban sprawl has been observed and studied since then. Many researchers have worked on estimating the density gradient and find evidence of the decentralization of population and employment due to technology and transportation innovations, rising real incomes, and "flight from blight" (Mills 1972, Edmonston 1975, Mieszkowski 1991, Glaeser and Kahn 2004). However, recent evidence suggests a reversal: center cities are gaining population. Millennials as "the creative class" prefer living in center cities (Florida 2002). Couture and Handbury (2016) find almost all large American cities have experienced large increases in young professionals near central business districts (CBD) since 2000. Bogin et. al. (2018) finds larger house price appreciation in areas closer to the city center within large cities. This literature has been based on changes in population density or the slope of the housing asset price gradient.

This paper adds to the research by providing direct evidence documenting the shift of the housing price gradient using both the asset price of the owner-occupied market and the rental price of the rental market for a wide range of metropolitan areas in the U.S. over a 30 year period. The comprehensive information contained in AHS facilitates construction of a panel of house price, average appreciation and appreciation rate in both the owner-occupied and rental market for over 100 MSAs during 1985-2013. Because this is panel data, it is relatively easy to control for the quality characteristics of housing units and to avoid the sample selection bias of repeated sales method and the omitted variable bias of the hedonic estimation method. The changes of house price ratio and appreciation differential between the center city and the suburbs reflect the shift of house price gradient over time.

Three main stylized facts are found. First, both asset and rental prices increased at a faster rate in the center city relative to suburbs, suggesting the steepening of house price gradients in both markets over the sample period. Second, regions have not all followed the general trend. For the owner-occupied market, asset price in center city stayed stable relative to suburbs in the Midwest, but grew relative to the suburbs in other regions. Whereas in the rental market, all regions experienced comparable increases in the steepness of the rent gradient except in the Northeast. Third, the house price gradient, whether measured using asset or rental prices, increased in slope fastest in big cities with high GDP and large population. These tests demonstrate that the steepening of rental price gradient and that of asset price gradient are comparable in terms of the average annual growth rate of the slopes and its correlation with region, GDP and population. It provides support for the academic research on causes of gentrification and urban revival, from the rental market perspective and on a disaggregated geographic level.

Another contribution of this study is to show that SUM can well explain the empirically observed phenomenon of city revival and gentrification. No other assumptions (which are often made) are needed, such as different housing preferences of the younger generations and differentiation between city amenities and suburban amenities. The Muth-Mills equation predicts that the rate at which house price falls with the distance to CBD is positively related to congestion but negatively related to housing consumption. Empirical tests using a specially constructed panel data set of U.S. metropolitan areas confirmed the prediction in the owner-occupied market. The rising trend in asset price ratio is entirely due to the changing transportation conditions. Asset price ratio rises by 0.9 (37%-41% steeper than “no delay” situation) if total annual congestion delay extends by 1 billion hours or by 0.06 if total annual congestion cost increases by 1 billion dollars. And in terms of the ratio of asset prices per square foot, 1 billion more hours of total annual congestion delay is association with an increase in it by 1.7 (18%-23% steeper than “no delay” situation), and 1 billion more dollars of total annual congestion cost pushes it up by 0.1. However, changes in rental price gradient do not conform to the expectations of SUM. This leaves a puzzle regarding the relation between the standard urban model and the movement of the rental price gradient.

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Figures and Tables

Figure 1: Normalized House price indices: comparing the national average asset prices from AHS with Case-Shiller index and FHFA HPI (2013 = 100)

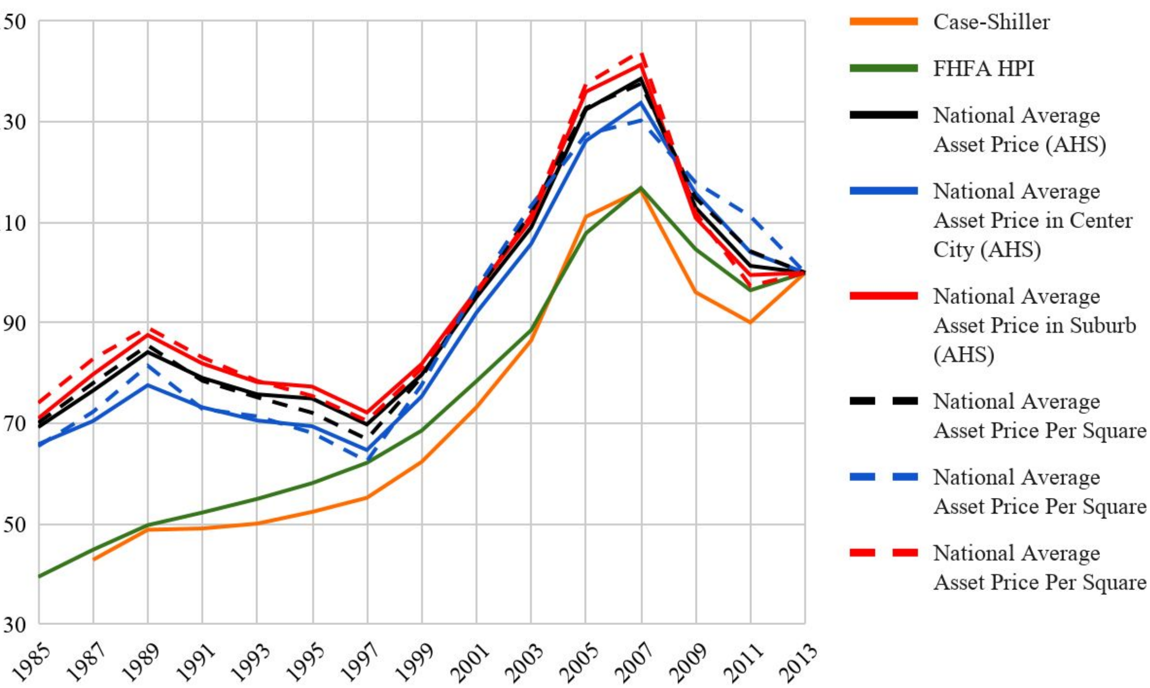

Figure 2: Changes in national average house price ratios between center city and suburb 1985-2013

Figure 3: Average annual house price appreciation rates on national level

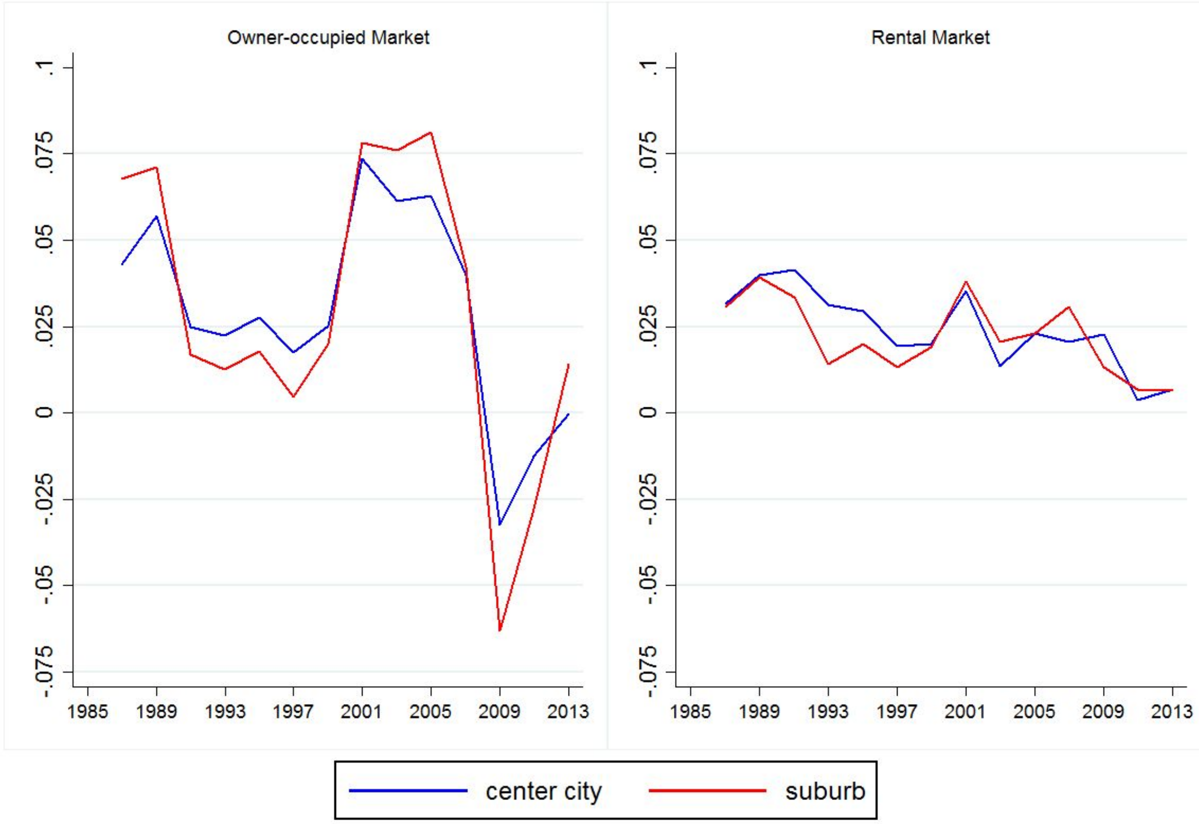

Table 1 : Correlation among national average asset price (AHS), FHFA HPI and Case-Shiller index

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1)	1							
(2)	0.991	1						
(3)	0.997	0.977	1					
(4)	0.997	0.993	0.991	1				
(5)	0.975	0.991	0.956	0.986	1			
(6)	0.992	0.968	0.998	0.987	0.946	1		
(7)	0.910	0.944	0.882	0.904	0.928	0.857	1	
(8)	0.938	0.960	0.917	0.931	0.941	0.896	0.992	1

Note: The table shown the correlation among (1) national average asset price from AHS, (2) national average asset price in center city from AHS, (3) national average asset price in suburbs from AHS, (4) national average asset price per square foot from AHS, (5) national average asset price per square foot in center city from AHS, (6) national average asset price per square foot in suburbs from AHS, (7) FHFA HPI, and (8) Case-Shiller index over 1985-2013.

Table 2: Tests on the time trend of the shift of asset price gradient

Dep. Var.		Asset Price Ratio				Ratio of Asset Price Per Square Foot		
Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
year	0.003***	0.007**	0.005***	0.007***	0.005***	0.007**	0.008***	0.009***
	[0.001]	[0.003]	[0.001]	[0.001]	[0.002]	[0.003]	[0.002]	[0.002]
Midwest		-0.006*				-0.001		
		[0.003]				[0.004]		
West		-0.003				-0.003		
		[0.004]				[0.004]		
Northeast		-0.004				-0.001		
		[0.003]				[0.005]		
Upper-middle GDP			-0.003				-0.001	
			[0.002]				[0.004]	
Lower-middle GDP			0.006				-0.004	
			[0.004]				[0.005]	
Low GDP			-0.008**				-0.012***	
			[0.003]				[0.004]	
Upper-middle Population				-0.006***				-0.006*
				[0.002]				[0.003]
Lower-middle Population				-0.006				-0.008**
				[0.005]				[0.004]
Low Population				-0.011*				-0.016*
				[0.006]				[0.009]
Constant	0.582***	0.628***	0.875***	0.810***	0.937***	0.936***	1.410***	0.892***
	[0.016]	[0.021]	[0.048]	[0.086]	[0.022]	[0.035]	[0.058]	[0.121]
R^2	0.65	0.65	0.66	0.66	0.44	0.44	0.45	0.45
N	1,139	1,139	1,139	1,139	1,139	1,139	1,139	1,139

* $p<0.1$; ** $p<0.05$; *** $p<0.01$

Note: This table reports the regressions results on the time trend of the shift of asset price gradient. The slope of asset price gradient is measured as asset price ratio between center city and suburbs in model (1)-(4), and as ratio of asset price per square foot in model (5)-(8). The sample covers 137 MSAs over 1985-2013 using data from American Housing Survey, which is conducted every other year. Regressions are conducted following equation (11)-(18). Dependent variable "year" is the time trend with year 1985 coded as 0, year 1987 coded as 2, and so and so forth. Each of the other dependent variables listed above represents an interactive term of the time trend and that dummy variable. Metropolitan areas are pooled in model (1) and (5), labeled by region with the South as the reference in model (2) and (6), ranked by real GDP in 2013 with the top quarter as the reference in model (3) and (7), and ranked by population in 2013 with the top quarter as the reference in model (4) and (8). MSA fixed effects are included in all models. Standard errors are clustered by MSA.

Table 3: Tests on the time trend of the shift of rental price gradient

Dep. Var.	Rental Price Ratio				Ratio of Rental Price Per Square Foot			
Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
year	0.005***	0.006***	0.005***	0.006***	0.001	0.002	0.003	0.003
	[0.001]	[0.001]	[0.001]	[0.001]	[0.002]	[0.003]	[0.004]	[0.002]
Midwest		-0.001				0.003		
		[0.002]				[0.004]		
West		0.000				0.002		
		[0.002]				[0.004]		
Northeast		-0.004**				-0.008		
		[0.002]				[0.007]		
Upper-middle GDP			0.001				0.001	
			[0.001]				[0.005]	
Lower-middle GDP			-0.003*				-0.008*	
			[0.002]				[0.004]	
Low GDP			-0.001				-0.006	
			[0.003]				[0.005]	
Upper-middle Population				-0.000				-0.003
				[0.002]				[0.005]
Lower-middle Population				-0.004**				-0.004
				[0.002]				[0.004]
Low Population				-0.005				-0.001
				[0.003]				[0.007]
Constant	0.922***	0.960***	0.755***	0.770***	1.176***	1.274***	1.143***	1.088***
	[0.010]	[0.016]	[0.016]	[0.021]	[0.024]	[0.073]	[0.032]	[0.054]
R^2	0.54	0.54	0.54	0.55	0.50	0.51	0.51	0.50
N	1,138	1,138	1,138	1,138	1,138	1,138	1,138	1,138

* p<0.1; ** p<0.05; *** p<0.01

Note: This table reports the regressions results on the time trend of the shift of rental price gradient. The slope of rental price gradient is measured as rental price ratio between center city and suburbs in model (1)-(4), and as ratio of rental price per square foot in model (5)-(8). The sample covers 137 MSAs over 1985-2013 using data from American Housing Survey, which is conducted every other year. Regressions are conducted following equation (11)-(18). Dependent variable "year" is the time trend with year 1985 coded as 0, year 1987 coded as 2, and so and so forth. Each of the other dependent variables listed above represents an interactive term of the time trend and that dummy variable. Metropolitan areas are pooled in model (1) and (5), labeled by region with the South as the reference in model (2) and (6), ranked by real GDP in 2013 with the top quarter as the reference in model (3) and (7), and ranked by population in 2013 with the top quarter as the reference in model (4) and (8). MSA fixed effects are included in all models. Standard errors are clustered by MSA.

Table 4: Tests of Time Trend of CAP Ratios (%) between Center City and Suburb

Model	(1)	(2)	(3)	(4)
Year Trend	0.064	0.176	0.326	0.300
	[0.260]	[0.296]	[0.257]	[0.222]
Midwest		0.811		
		[0.564]		
West		0.145		
		[0.540]		
Northeast		-1.602**		
		[0.750]		
Upper-middle GDP			-0.641	
			[0.527]	
Lower-middle GDP			-0.340	
			[0.875]	
Low GDP			-0.210	
			[1.015]	
Upper-middle Population				-0.563
				[0.548]
Lower-middle Population				-0.822
				[1.340]
Low Population				0.834
				[0.513]
Constant	118.838***	137.861***	123.675***	123.014***
	[3.320]	[8.791]	[5.870]	[6.391]
R^2	0.17	0.18	0.17	0.17
N	1,081	1,081	1,081	1,081

* p<0.1; ** p<0.05; *** p<0.01

This table reports the regressions results on the time trend of the capitalization rate ratio between center city and suburbs. The sample covers 75 MSAs in the US using data from AHS, which is conducted every other year over 1985-2013. Regressions are conducted following equation (24)-(27). Dependent variable "year trend" is the time trend with year 1985 coded as 0, year 1987 coded as 2 and so on and so forth. Each of the other dependent variables listed above in the table represents an interactive term of the time trend and that specific dummy variable. In model (2), South is used as the reference. In model (3), the highest 25% in terms of real GDP per capital in 2013 is used as the reference. In model (4), the largest 25% in terms of population in 3012 is used as the reference. MSA fixed effects are included in all models. Standard errors are clusted by MSA in all models.

Table 5: Tests of Changing Asset Price Gradient on Congestion and Income

Dep. Var.		Asset Price Ratio				Ratio of Asset Price Per Square		
Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
congestion delay (billion hrs)	0.892**				1.678***			
	[0.379]				[0.617]			
per commuter congestion delay (000 hrs)		1.269				6.645*		
		[2.052]				[3.520]		
congestion cost (billion $)			0.061***				0.104***	
			[0.018]				[0.020]	
per commuter congestion cost (000 $)				0.102				0.216**
				[0.065]				[0.105]
per capita personal income (million $)	0.160	1.162	0.723	1.507	-1.164	-0.095	0.012	1.394
	[2.080]	[2.103]	[1.973]	[1.936]	[3.427]	[4.466]	[3.877]	[4.737]
year trend	0.001	0.001	0.001	0.000	0.003	-0.000	0.003	0.000
	[0.003]	[0.003]	[0.003]	[0.003]	[0.004]	[0.005]	[0.005]	[0.005]
Constant	0.652***	0.599***	0.031	0.736***	1.418***	1.268***	-0.602**	0.536***
	[0.030]	[0.035]	[0.253]	[0.109]	[0.054]	[0.080]	[0.265]	[0.190]
R^2	0.68	0.67	0.68	0.67	0.49	0.47	0.48	0.48
N	854	854	854	854	854	854	854	854

* p<0.1; ** p<0.05; *** p<0.01

Note: This table demonstrates the empirical results of changing asset price gradient on congestion cost and city income. In model (1)-(4), the slope of the asset price gradient is measured as asset price ratio between center city and suburbs, and in model (5)-(8) it is measured by the ratio of asset price per square foot. Sample covers 62 metropolitan areas over 1985- 2013. Congestion are measured by four alternatives: (1) total congestion delay in billion hours, (2) per commuter congestion delay in thousand hours, (3) total congestion cost in billion dollars, and (4) per commuter congestion cost in thousand dollars. Data used to construct these measures are Urban Mobility Scoreboard from A&M Transportation Institute. City income is measured as per capita personal income in million dollars from BEA. The year trend variable is coded as: 1985 = 0, 1987 = 2, …, 2013 = 28. MSA fixed effects are included in all models. Standard errors are clustered by MSA.

Table 6: Tests of Changing Rent Gradient on Congestion and City Income

Dep. Var.		Rental Price Ratio				Ratio of Rental Price Per Square		
Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
congestion delay (billion hrs)	0.041				0.883			
	[0.217]				[0.548]			
per commuter congestion delay (000 hrs)		-0.596				2.070		
		[1.640]				[3.488]		
congestion cost (billion $)			-0.002				0.022	
			[0.011]				[0.026]	
per commuter congestion cost (000 $)				-0.033				-0.114
				[0.048]				[0.110]
per capita personal income (million $)	-1.799	-1.627	-1.724	-1.775	-10.135	-9.300	-9.143	-9.016
	[1.743]	[1.703]	[1.789]	[1.770]	[9.861]	[9.998]	[10.243]	[10.157]
year trend	0.015***	0.016**	0.016***	0.017***	0.022	0.021	0.023	0.028
	[0.005]	[0.007]	[0.005]	[0.006]	[0.020]	[0.023]	[0.021]	[0.023]
constant	0.737***	0.751***	0.940***	1.292***	1.565***	1.482***	1.298***	0.976***
	[0.026]	[0.054]	[0.024]	[0.013]	[0.170]	[0.210]	[0.160]	[0.079]
R^2	0.56	0.56	0.56	0.56	0.55	0.55	0.55	0.55
N	853	853	853	853	853	853	853	853

* $p<0.1$; ** $p<0.05$; *** $p<0.01$

Note: This table demonstrates the empirical results of changing rental price gradient on congestion and city income. In model (1)-(4), the slope of the rent gradient is measured as rental price ratio between center city and suburbs, and in model (5)-(8) it is measured by the ratio of rental price per square foot. Sample covers 62 metropolitan areas over 1985- 2013. Congestion are measured by four alternatives: (1) total congestion delay in billion hours, (2) per commuter congestion delay in thousand hours, (3) total congestion cost in billion dollars, and (4) per commuter congestion cost in thousand dollars. Data used to construct these measures are Urban Mobility Scoreboard from A&M Transportation Institute. City income is measured as per capita personal income in million dollars from BEA. The year trend variable is coded as: 1985 = 0, 1987 = 2, …, 2013 = 28. MSA fixed effects are included in all models. Standard errors are clustered by MSA.

Table 7: Tests of Changing Asset Price Gradient on Congestion and Income with Region Interactive Terms

Dep. Var.		Asset Price Ratio				Ratio of Asset Price Per Square Foot		
Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
congestion delay (billion hrs)	0.861**				1.704***			
	[0.348]				[0.545]			
per commuter congestion delay (000 hrs)		0.995				6.523*		
		[2.030]				[3.331]		
congestion cost (billion $)			0.057***				0.103***	
			[0.015]				[0.020]	
per commuter congestion cost (000 $)				0.077				0.215**
				[0.060]				[0.104]
per capita personal income (million $)	1.575	2.597	2.185	2.825	-1.125	0.096	0.185	1.393
	[2.057]	[1.904]	[1.933]	[1.813]	[3.421]	[4.504]	[3.944]	[4.677]
year trend	0.004	0.004	0.003	0.003	0.006	0.002	0.005	0.002
	[0.005]	[0.005]	[0.005]	[0.004]	[0.005]	[0.006]	[0.006]	[0.006]
midwest	-0.005	-0.006	-0.005	-0.005	-0.002	-0.002	-0.001	-0.002
	[0.004]	[0.004]	[0.004]	[0.004]	[0.003]	[0.004]	[0.003]	[0.004]
west	-0.005	-0.005	-0.004	-0.005	-0.006	-0.006	-0.005	-0.005
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
northeast	-0.007**	-0.008*	-0.007**	-0.007*	-0.002	-0.002	-0.002	-0.001
	[0.004]	[0.004]	[0.004]	[0.004]	[0.006]	[0.007]	[0.006]	[0.007]
Constant	0.944***	0.885***	0.074	1.233***	1.188***	0.956***	-0.538*	1.275***
	[0.041]	[0.067]	[0.225]	[0.030]	[0.057]	[0.100]	[0.295]	[0.043]
R^2	0.69	0.68	0.69	0.68	0.49	0.48	0.49	0.48
N	854	854	854	854	854	854	854	854

* p<0.1; ** p<0.05; *** p<0.01

Note: This table demonstrates the empirical results of changing asset price gradient on congestion and city income with the interactive terms of time trend and region (south as the reference). In model (1)- (4), the slope of the rent gradient is measured as asset price ratio between center city and suburbs, and in model (5)-(8) it is measured by the ratio of asset price per square foot. Sample covers 62 metropolitan areas over 1985- 2013. Congestion are measured by four alternatives: (1) total congestion delay in billion hours, (2) per commuter congestion delay in thousand hours, (3) total congestion cost in billion dollars, and (4) per commuter congestion cost in thousand dollars. Data used to construct these measures are Urban Mobility Scoreboard from A&M Transportation Institute. City income is measured as per capita personal income in million dollars from BEA. The year trend variable is coded as: 1985 = 0, 1987 = 2, …, 2013 = 28. "Midwest", "west" and "northeast" represent the regional-year trend interactive terms. MSA fixed effects are included in all models. Standard errors are clustered by MSA in all models.

Table 8: Tests of Changing Rental Price Gradient on Congestion and Income with Region Interactive Terms

Dep. Var.		Rental Price Ratio			Ratio of Rental Price Per Square Foot			
Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Congestion Delay (billion hrs)	0.022				0.917*			
	[0.271]				[0.512]			
Per Commuter Congestion Delay (000 hrs)		-0.577				2.968		
		[1.720]				[3.366]		
Congestion Cost (billion $)			-0.003				0.029	
			[0.015]				[0.029]	
Per Commuter Congestion Cost (000 $)				-0.048				-0.111
				[0.051]				[0.104]
Per Capita Personal Income (million $)	-0.507	-0.376	-0.450	-0.512	-6.805	-6.056	-5.834	-5.623
	[1.745]	[1.713]	[1.801]	[1.775]	[8.699]	[8.831]	[9.057]	[9.041]
Year Trend	0.008***	0.009**	0.008***	0.009***	0.008	0.006	0.008	0.011
	[0.002]	[0.003]	[0.002]	[0.003]	[0.010]	[0.011]	[0.010]	[0.011]
Midwest	-0.002	-0.002	-0.002	-0.002	0.004	0.004	0.004	0.003
	[0.002]	[0.002]	[0.002]	[0.002]	[0.005]	[0.005]	[0.005]	[0.005]
West	-0.001	-0.001	-0.001	-0.001	0.001	0.002	0.002	0.001
	[0.003]	[0.003]	[0.003]	[0.003]	[0.005]	[0.005]	[0.005]	[0.005]
Northeast	-0.005**	-0.005**	-0.005**	-0.005**	-0.010	-0.010	-0.010	-0.010
	[0.002]	[0.002]	[0.002]	[0.002]	[0.006]	[0.006]	[0.006]	[0.007]
Constant	0.967***	0.974***	0.863***	1.273***	1.401***	1.321***	1.232***	0.922***
	[0.027]	[0.039]	[0.030]	[0.023]	[0.173]	[0.185]	[0.113]	[0.063]
R^2	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56
N	853	853	853	853	853	853	853	853

* $p<0.1$; ** $p<0.05$; *** $p<0.01$

Note: This table demonstrates the empirical results of changing rental price gradient on congestion and city income with the interactive terms of time trend and region (south as the reference). In model (1)- (4), the slope of the rent gradient is measured as rental price ratio between center city and suburbs, and in model (5)-(8) it is measured by the ratio of rental price per square foot. Sample covers 62 metropolitan areas over 1985- 2013. Congestion are measured by four alternatives: (1) total congestion delay in billion hours, (2) per commuter congestion delay in thousand hours, (3) total congestion cost in billion dollars, and (4) per commuter congestion cost in thousand dollars. Data used to construct these measures are Urban Mobility Scoreboard from A&M Transportation Institute. City income is measured as per capita personal income in million dollars from BEA. The year trend variable is coded as: 1985 = 0, 1987 = 2, …, 2013 = 28. "Midwest", "west" and "northeast" represent the regional-year trend interactive terms. MSA fixed effects are included in all models. Standard errors are clustered by MSA in all models.

Table 9: Tests of Changing Asset Price Gradient on Congestion and Income with GDP-Time Trend Interactive Terms

Dep. Var.	Asset Price Ratio				Ratio of Asset price Per Square Foot			
Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Congestion Delay (billion hrs)	0.797**				1.596**			
	[0.364]				[0.643]			
Per Commuter Congestion Delay (000 hrs)		0.909				6.156**		
		[1.870]				[3.065]		
Congestion Cost (billion $)			0.049***				0.105***	
			[0.017]				[0.020]	
Per Commuter Congestion Cost (000 $)				0.076				0.257**
				[0.064]				[0.097]
Per Capita Personal Income (million $)	0.435	-0.078	0.170	0.033	-4.505*	-6.302**	-5.022*	-5.382*
	[2.068]	[1.991]	[1.928]	[1.827]	[2.672]	[2.773]	[2.536]	[2.866]
Year Trend	0.001	0.004	0.002	0.003	0.009**	0.012**	0.012***	0.013***
	[0.004]	[0.003]	[0.003]	[0.003]	[0.004]	[0.005]	[0.004]	[0.004]
Upper-middle GDP	-0.000	-0.002	-0.001	-0.002	0.003	-0.002	0.000	-0.002
	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.004]	[0.003]	[0.004]
Lower-middle GDP	0.007*	0.006	0.006	0.005	-0.007	-0.010**	-0.010**	-0.012**
	[0.004]	[0.005]	[0.004]	[0.005]	[0.004]	[0.005]	[0.004]	[0.005]
Low GDP	-0.005	-0.007**	-0.006*	-0.007**	-0.013***	-0.018***	-0.016***	-0.019***
	[0.003]	[0.003]	[0.003]	[0.003]	[0.004]	[0.004]	[0.004]	[0.004]
Constant	0.631***	0.611***	0.211	0.791***	0.918***	0.833***	-0.580**	0.500***
	[0.067]	[0.066]	[0.237]	[0.107]	[0.070]	[0.090]	[0.276]	[0.167]
R^2	0.69	0.69	0.69	0.69	0.50	0.50	0.51	0.50
N	854	854	854	854	854	854	854	854

* $p<0.1$; ** $p<0.05$; *** $p<0.01$

Note: This table demonstrates the empirical results of changing asset price gradient on congestion and city income with the interactive terms of time trend and quarters of real GDP per capita in 2013 (top 25% as the reference). In model (1)- (4), the slope of the asset price gradient is measured as asset price ratio between center city and suburbs, and in model (5)-(8) it is measured by the ratio of asset price per square foot. Sample covers 62 metropolitan areas over 1985- 2013. Congestion are measured by four alternatives: (1) total congestion delay in billion hours, (2) per commuter congestion delay in thousand hours, (3) total congestion cost in billion dollars, and (4) per commuter congestion cost in thousand dollars. Data used to construct these measures are Urban Mobility Scoreboard from A&M Transportation Institute. City income is measured as per capita personal income in million dollars from BEA. The year trend variable is coded as: 1985 = 0, 1987 = 2, …, 2013 = 28. "Midwest", "west" and "northeast" represent the regional-year trend interactive terms. MSA fixed effects are included in all models. Standard errors are clustered by MSA in all models.

Table 10: Tests of Changing Rental Price Gradient on Congestion and Income with GDP-Time Trend Interactive Terms

Dep. Var.		Rental Price Ratio				Ratio of Rental Price Per Square Foot		
Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Congestion Delay (billion hrs)	0.172				0.468			
	[0.191]				[0.505]			
Per Commuter Congestion Delay (000 hrs)		-0.509				1.935		
		[1.596]				[3.359]		
Congestion Cost (billion $)			0.005				0.014	
			[0.009]				[0.022]	
Per Commuter Congestion Cost (000 $)				-0.023				-0.062
				[0.050]				[0.108]
Per Capita Personal Income (million $)	-1.111	-1.094	-1.177	-1.168	-16.746**	-17.299**	-16.926*	-16.902*
	[1.574]	[1.686]	[1.630]	[1.630]	[8.259]	[8.334]	[8.562]	[8.560]
Year Trend	0.006**	0.007**	0.006**	0.007***	0.026***	0.027**	0.028***	0.029***
	[0.002]	[0.003]	[0.002]	[0.002]	[0.009]	[0.011]	[0.010]	[0.011]
Upper-middle GDP	0.002	0.002	0.002	0.002	-0.006	-0.007*	-0.007	-0.007*
	[0.002]	[0.002]	[0.002]	[0.002]	[0.005]	[0.004]	[0.004]	[0.004]
Lower-middle GDP	-0.002	-0.002	-0.002	-0.002	-0.016***	-0.017***	-0.017***	-0.017***
	[0.002]	[0.002]	[0.002]	[0.002]	[0.004]	[0.004]	[0.004]	[0.004]
Low GDP	0.003	0.002	0.002	0.002	-0.014**	-0.016**	-0.015**	-0.016**
	[0.005]	[0.005]	[0.005]	[0.005]	[0.007]	[0.007]	[0.007]	[0.007]
Constant	0.768***	0.771***	0.931***	1.265***	1.415***	1.388***	1.479***	1.143***
	[0.032]	[0.034]	[0.027]	[0.066]	[0.137]	[0.151]	[0.104]	[0.115]
R^2	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56
N	853	853	853	853	853	853	853	853

* p<0.1; ** p<0.05; *** p<0.01

Note: This table demonstrates the empirical results of changing rental price gradient on congestion and city income with the interactive terms of time trend and quarters of real GDP per capita in 2013 (top 25% as the reference). In model (1)- (4), the slope of the rent gradient is measured as rental price ratio between center city and suburbs, and in model (5)-(8) it is measured by the ratio of rental price per square foot. Sample covers 62 metropolitan areas over 1985- 2013. Congestion are measured by four alternatives: (1) total congestion delay in billion hours, (2) per commuter congestion delay in thousand hours, (3) total congestion cost in billion dollars, and (4) per commuter congestion cost in thousand dollars. Data used to construct these measures are Urban Mobility Scoreboard from A&M Transportation Institute. City income is measured as per capita personal income in million dollars from BEA. The year trend variable is coded as: 1985 = 0, 1987 = 2, …, 2013 = 28. "Midwest", "west" and "northeast" represent the regional-year trend interactive terms. MSA fixed effects are included in all models. Standard errors are clustered by MSA in all models.