NBER WORKING PAPER SERIES

THE DYNAMICS OF HOUSING PRICES

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Working Paper 20418
http://www.nber.org/papers/w20418

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
August 2014

We acknowledge the helpful comments from Su Han Chan, Sing Tien Foo, David Frame, Richard Gil, Christopher Parsons and seminar participants at Chinese Academy of Sciences, Chinese Academy of Social Sciences, Colorado State University, Johns Hopkins University, Massey University, Shanghai University of Finance and Economics, 2009 AREUEA/AsRES Joint Meeting and 2010 GCREC Annual Meeting. We thank Jiajin Chen, Yalan Feng and Mariya Letdin for their research assistance on this paper. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 20418
August 2014
JEL No. R21,R31

ABSTRACT

We analyze the prices of owner-occupied housing in 97 metropolitan areas between 1980 and 2011. Our tests indicate that price changes exhibit positive serial correlation at the one year intervals, with subsequent reversals of price changes over longer intervals. Consistent with our simple model, regional differences in observed price patterns reflect differences in the serial correlation of the demand shocks as well as the elasticity of supply responses.

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1. Introduction

The price process of real assets, in particular real estate, is of interest to financial economists for a number of reasons. For example, since real estate is often used as collateral for loans that are used for other types of corporate investments, changes in real estate prices can affect the level of investment expenditures more generally. This relation between real estate prices and corporate investment choices is examined in Gan (2007), who reports that between 1994 and 1998 Japanese manufacturing firms experienced a 0.8% decline in their investment rates for every 10% decrease in land value. In a more recent study of U.S. firms over the 1993-2007 time period, Chaney, Sraer and Thesmar (2012) find that a 20% decline in real estate prices reduces the aggregate investment of public firms by 3%. More recent papers examine how housing prices influence entrepreneurs, who use their houses as collateral to start new businesses.[1] Finally, as the 2008 financial crisis illustrates, since real estate represents a large fraction of the overall capital in the economy, financial institutions are particularly vulnerable to the changes in the value of real estate.[2]

In this paper, we empirically examine the price process of residential real estate. In contrast to financial securities, whose prices tend to approximate a random walk, our research suggests that housing price changes are positively correlated over yearly intervals, with partial reversals of price changes over longer horizons.[3] As we show, these serial correlations are related to a variety of city characteristics that relate to the persistence in the housing demand growth and the elasticity of the supply of new housing.

To motivate our empirical tests, we present a reduced form four-date model that illustrates the economic forces that influence the price process. The model includes a number of features, which we believe approximate reality. The first feature is that demand growth within a metropolitan area is positively serially correlated. The idea is that a city can build on its past success. For example, a positive shock to a large manufacturing industry within a city leads to an immediate increase in demand for housing from the workers hired directly in the manufacturing sector, and then a subsequent increase in demand from workers (e.g. teachers and restaurant workers) who provide services to individuals in the manufacturing sector. The second feature is that construction takes time, which means that the supply of housing responds to changes in price with a lag. In addition, because tearing down houses only makes sense in extreme situations, there is likely to be an asymmetry in the reaction to positive and negative shocks.

Finally, we assume that there are frictions in the real asset markets that limit the ability of investors to arbitrage away the short-term predictability of prices. In the case of owner occupied housing there are transaction costs associated with buying and selling and the cost of renting out a home that one owns but does not occupy. To capture these costs we assume that housing is constrained to be owner occupied, and that buyers and sellers are myopic. Specifically, they do not buy more housing today in anticipation of a price increase in the future. A plausible rationale for this assumption, which has been explored in prior research,[4] is that homeowners tend to be financially constrained. Although the extreme form of this last assumption is not needed to generate serially correlated prices, it considerably simplifies the model and results in simple closed form solutions for prices in all periods.[5]

Within this setting a positive demand shock triggers an immediate price response, as well as a subsequent response on the next date that is generated because demand is expected to continue to grow. The adjustment on the second date depends on the supply response. Because it takes time to build, this price response results in additional supply in both the second and third periods. As we show, price changes in this simple setting tend to be positively correlated between the first and second periods, but negatively correlated between the first and third periods. The magnitudes of these serial correlations depend on the persistence of the demand shocks and the elasticity of the supply response on the second and third dates.

Using quarterly U.S. metropolitan-level housing market data that covers 97 MSAs from 1980 to 2011 we empirically explore the implications of our model. Our sample is divided into a pre- (before 2007) and post- (after 2007) crisis periods. The post-crisis period is of interest because it allows us to explore the implications of negative economic shocks (prior to the crisis there were very few negative yearly price changes). However, the volume of transactions significantly decrease in a number of housing markets in the post-2007 period, so these observations may be less reliable.

Consistent with the model implications, housing prices are positively serially correlated over yearly intervals. We also document evidence of a longer-term reversal, which is also consistent with the model. However, the magnitude of the reversal is actually stronger in the post-2007 period. This last observation is inconsistent with our model, because we do not expect significant supply responses subsequent to falling housing prices, suggesting that there may have been some over-reaction during the crisis period.

The observed serial correlations tend to differ across MSAs, which is the focus of most of our analysis. In particular, at least prior to the crisis, proxies for demand persistence and supply rigidities in different MSAs partially explain the observed differences in housing price dynamics across MSAs. Specifically, we find that larger cities, whose demand shocks tend to exhibit stronger positive short-run serial correlation, tend to exhibit stronger positive short-run serial correlations in property appreciation rates. In addition, cities that put constraints on the initiation and completion of development projects, i.e., those with stringent regulatory constraints and high population densities, tend to exhibit stronger positive short-run serial correlations and more negative long-run serial correlations in property appreciation rates.

In addition to the previously cited research on the interaction of real estate prices and real investment choices, our research is related to a number of papers in the housing literature. Topel and Rosen (1988) provide the seminal analysis of the effect of demand shocks on housing construction. In addition to their empirical work, that shows that construction reacts to prices with a lag, they provide a fully rational model with forward looking builders who respond to demand shocks with a lag because of adjustment costs. Although Topel and Rosen provide a much more detailed analysis of the implications of adjustment costs, they do not explore how these costs influence the time series of price appreciation rates, which is our central focus. Case and Shiller (1988, 1989), however, do consider the time series pattern of housing prices, and were the first to show that housing prices exhibit positive serial correlation over yearly intervals. They attribute the serial correlation to investors' "irrational expectations" about price growth persistence. A more recent paper by Piazzesi and Schneider (2009) provide survey data taken during the housing boom in the 2000's that suggests that homeowners tend to irrationally extrapolate from past price trends and provide a theoretical model that indicates that because of an absence of short-selling, a small number of optimistic individuals can have a large effect on prices. In contrast, the homeowners in our model are myopic but are not necessarily irrational, and in addition to the observed positive serial correlation at yearly intervals, our model generates price changes that are partially reversed in the future.[6]

Capozza, Hendershott and Mack (2004) also examine how the characteristics of urban areas influence serial correlation. While they do not provide a model, they estimate a price process that assumes that in addition to serially correlated price changes, prices in each metropolitan area revert towards a long-run equilibrium level. Nneji, Brooks, and Ward (2013) examine whether deviations of real estate prices from their fundamentals can be caused by two types of bubbles: intrinsic bubbles and rational speculative bubbles. Glaeser, Gyourko and Saiz (2008) and Saiz (2010) consider geographical features of metropolitan areas that affect the elasticity of housing supply and examine how these features influence housing prices. We also consider geography and supply elasticity; however, in contrast to Glaeser, Gyourko and Saiz (2008) and Saiz (2010), our focus is more on shorter term supply rigidities and its effect on shorter term price patterns, rather than on the longer term effects of geography on prices.

More recently, in work that is contemporaneous with ours, Glaeser, Gyourko, Morales and Nathanson (2011) develop and calibrate a model of price movements in the housing market. In contrast to our model, they model the production choice of builders as well as the location choice of homeowners. However, the structure that they put on the choices of homeowners (they each buy one housing unit) makes the model and its implications very similar to our simple reduced form model.[7] Moreover, they do not focus on cross city differences, which is the focus of our paper.

Finally, this research is tangentially related to research that examines the return patterns of common stocks. In particular, Jegadeesh and Titman (1993) document a pattern of momentum over 3 to 12 month intervals and reversals over longer intervals and Hong, Lim and Stein (1999) attributes these patterns to slow moving information. We would expect that slowly moving information is more relevant for real estate than for the stock market, and that it should be particularly relevant in smaller urban areas with less active real estate markets. However, we find that the shorter term momentum is actually stronger in larger cities, suggesting that the higher serial correlation in demand shocks, which is a feature of our model, may be more important for real estate price patterns than slow moving information, which is not a feature of our model.

The next section presents our model and derives testable hypotheses. Section 3 describes our empirical study methods, data gathering procedure and summary statistics of the data used. We test our model implications in sections 4 and 5. Section 6 contains our conclusions.

2. Model and Hypotheses

This section presents a four-date model that provides conditions under which property appreciation rates can exhibit positive and negative serial correlations. In this simple reduced-form model, the buyers and sellers, either because of their limited rationality or because of credit constraints, are myopic. In other words, their buying and selling choices are not influenced by the expectations of future price changes, but based only on their current consumption needs. Consequently, the price is determined by current supply and demand conditions.

We specify the demand function for housing as

$$D_t = z_t - bp_t, \tag{1}$$

where at date t ($t = 0, 1, 2,$ or 3), demand D_t is positively affected by an exogenous shock, which is captured by changes in the intercept (z_t) of the demand function, and is negatively affected by the current housing price, p_t. The slope, b, measures the sensitivity of the demand change to the price change. We assume that demand shocks in two consecutive periods can be expressed as

$$\frac{z_t - z_{t-1}}{z_{t-1}} = x_1 \left(\frac{z_{t-1} - z_{t-2}}{z_{t-2}}\right) + \sigma_t, \qquad (2)$$

where x_1 captures the serial correlation of two consecutive demand shocks and σ_t is a random error term. We assume that there is positive serial correlation in the demand shock between the first and the second periods, that is, $x_1 > 0$, which is consistent with the time-series properties of aggregate output reported in the literature.[8]

The supply of housing, S_t, is exogenously determined at $t = 0$, but will endogenously grow in later periods depending on the realization of house prices. In our model, the change in the supply of housing S_t is determined as a function of the price changes on the previous dates, and is expressed as

$$\frac{S_t - S_{t-1}}{S_{t-1}} = \delta_t + \sum_{i=1}^{t-1} \frac{1}{k_i} \left(\frac{p_{t-i} - p_{t-i-1}}{p_{t-i-1}}\right), \qquad (3)$$

where k_i is a supply rigidity factor, which measures the magnitude of the supply change in response to the i-th period lagged appreciation rate, and δ_t captures the natural growth in supply (or, the replacement of depreciated properties).[9] Correspondingly, $\frac{1}{k_i}$ captures the sensitivity of supply change to changes in housing prices. For simplicity we are assuming that the relation between supply changes and price changes is linear. However, in our empirical work we will consider the possibility that supply responds to price increases more than to price decreases.

The above characterization of the supply function captures the idea that because construction takes time, supply reacts to price increases with a lag. Specifically, we assume that there is a partial response in one year and a further response in two years. As we just mentioned, these supply responses may be different in declining and growing markets and their magnitudes may also depend on various characteristics of cities that can influence the approval and development process. A large short-run supply rigidity factor k_1 means that the supply adjusts slowly to price increases. This will be the case in cities where the regulatory approval process is slow or in cities with dense populations where the construction process is difficult to control. However, it should be noted that, depending on the magnitude of the delay, supply will eventually enter the market at a later date. Given this, a larger short-run supply rigidity factor k_1 should lead to a smaller long-run supply rigidity factor k_2. To facilitate our later discussions, we define $y_2 = \frac{1}{k_2}$ as the long-run supply sensitivity factor.

Applying the market clearing condition to each of the four periods, we derive the equilibrium prices at the four dates as follows:

$$p_0^* = \frac{z_0 m}{b}, \tag{4}$$

$$p_1^* = \frac{z_0(e_1+m)}{b}, \tag{5}$$

$$p_2^* = \frac{z_0}{bk_1 m}\{k_1 m^2 + e_1^2 k_1 m x_1 + e_1[m(1 + k_1 + k_1 x_1) - 1]\}, \tag{6}$$

$$p_3^* = \frac{z_0}{b}\{(1 + e_1)(1 + e_1 x_1)(1 + e_1 x_1^2) - (1 - m)(1 + \frac{e_1}{k_1 m})\cdot$$

$$[1 + \frac{e_1}{k_2 m} + \frac{e_1(m(1+(1+e_1)k_1 x_1)-1)}{k_1^2 m(m+e_1)}]\}, \tag{7}$$

where $m = 1 - \frac{S_0}{z_0}$, and $e_1 = \frac{z_1 - z_0}{z_0}$.

An examination of the price changes derived from Equations (4) to (7) leads to Proposition 1.

Proposition 1: If housing demand and supply are characterized by Equations (1) to (3), price changes exhibit the following two patterns:

[I] The price changes from date 1 to date 2 are positively correlated with the price changes from date 0 to date 1 if the short-run supply rigidity factor (k_1) and the short-run serial correlation in the demand shock ($x_1 > 0$) satisfy the condition that $k_1 x_1 > \frac{(z_0 - bp_0)z_0}{bp_0 z_1}$. Furthermore, the magnitude of the one–period serial correlation of price changes is increasing in the serial correlation of demand shocks x_1 and the supply rigidity k_1.

[II] The price changes from date 2 to date 3 will be negatively correlated with the price changes from date 0 to date 1 if $\frac{p_3^* - p_2^*}{p_2^*} < \frac{(z_1 - z_0)a_1^2}{bp_0}$, where a_1 measures the sensitivity of the current appreciation rate to last period's appreciation rate. Furthermore, the magnitude of the negative correlation between the appreciate rate in the current period and the appreciation rate two periods earlier is increasing in the long-run supply sensitivity factor $y_2 = \frac{1}{k_2}$.

Proof. See Appendix A.

Proposition 1 illustrates that under fairly reasonable conditions, real estate price changes are likely to exhibit positive serial correlation over relatively short intervals. However, price changes partially reverse in the long run. This pattern arises because of the assumed persistence in the demand shocks combined with supply responses that take time. For example, prices may initially increase with a positive shock to demand, continue to increase as the demand shock persists, and then subsequently decrease as new supply comes on line. As our simple model illustrates, the magnitude of these price patterns are determined by the speed and strength of the supply response, which is likely to differ across cities. In addition, the price patterns are likely to be related to the overall state of the market, given that supply is likely to be more sensitive to the magnitude of price increases than decreases.

3. Empirical Tests and Sample Description

This section discusses our empirical tests and describes the characteristics of our sample. The first subsection describes our empirical tests. The second subsection details our data and the selection of proxy variables. The last subsection describes the characteristics of the Metropolitan Statistical Areas (MSAs) we use in our sample.

3.1. Empirical Tests

We run regressions using panel data to estimate the persistence of property appreciation rates and the degree to which that persistence is affected by serial correlations in demand and/or supply rigidity factors. These regressions include the property appreciation rate of each MSA as the dependent variable, a proxy for a contemporaneous demand shock, lagged appreciation rates, proxies for the serial correlation of demand shocks and supply rigidities, and the interactions of these proxies with past appreciation rates. The regressions take the following form:

$$r_{j,t} = \emptyset_G + \omega_{G1} r_{j,t-1} + \omega_{G2} r_{j,t-2} + \omega_{G3} r_{j,t-3} + \chi G_{j,t} + \theta_{G1}\left[r_{j,t-1} G_{j,t}\right]$$

$$+\theta_{G2}\left[r_{j,t-2} G_{j,t}\right] + \theta_{G3}\left[r_{j,t-3} G_{j,t}\right] + \gamma_G b_{j,t} + \sigma_G, \qquad (8)$$

where j is the MSA index, t is the year index, r_t is the annual appreciation rate at year t (we use overlapping year-on-year price changes calculated at each quarter), r_{t-i} is the $i-$year lagged annual appreciation rate, with $i = 1, 2$ or 3. $G \in \{x_1,\ k_1 \text{ or } k_2\}$ represents characteristics that proxy for the serial correlation of demand shocks or supply rigidity, $r_{t-i} G_t$ is the interaction between the proxy variable and the i −th lagged term of the appreciation rate, b_t is the annual growth rate of a fundamental economic variable at year t, which represents a contemporaneous demand shock, and σ_G is the error term. $\emptyset_G$ is the constant.

The coefficients of the 3 lagged appreciated rates, ω_{Gi} (where $i = 1,2,3$), tell us if the property appreciation rate of the current period is related to past appreciation rates. The coefficients of the three interaction variables θ_{Gi} (where $i = 1,2,3$) tell us if proxies for demand and supply characteristics affect the magnitude of the serial correlations in the property appreciation rates.

We use the Fama-MacBeth procedure (Fama and MacBeth (1973)) to estimate the coefficients of the panel regression and adjust the standard errors using the Newey-West method (Newey and West (1987)) modified for the use in a panel data set. (Petersen (2009) provides a detailed discussion on the trade-offs among different methods used for panel data regressions.)

3.2. Data and proxy variables

We start with the quarterly property appreciation rates for 381 U.S. Metropolitan Statistical Areas (based on 2004 MSA definitions). However, because of data limitations, we delete MSAs with short data series, leaving us with 97 MSAs covering all 50 states in the U.S.A over the sample period between 1980 Q1 to 2011 Q4. Data on the appreciation rates were provided by FHFA (Federal Housing Finance Agency, formerly known as the Office of Federal Housing Enterprise Oversight, or OFHEO). The FHFA quarterly housing price index is calculated using price changes on individual properties from repeat sales or refinancing on the same single-family houses whose mortgages have been purchased or securitized by Fannie Mae or Freddie Mac.[10] Although the sample of houses is limited, this is probably the most widely used housing price index because of its broad coverage of MSAs and long time periods.[11]

It should be noted that in contrast to financial market prices, there is a problem of stale housing prices. There are a couple of reasons why this may be the case. The most direct reason is that buyers and sellers tend to agree on a price prior to when the sale actually closes. In addition, after listing their houses, sellers may be slow to adjust the price of their houses to reflect new information. Each of these reasons is likely to generate some positive serial correlation in observed price indexes. However, given the typical time span between when offers are accepted and when the sale closes, and the very minor costs associated with adjusting prices to reflect new information, it is unlikely that these mechanical effects will induce serial correlation over intervals that go beyond a quarter. If this is indeed the case, the serial correlation that is generated from stale prices is eliminated in regressions that skip a quarter between the measurements of the appreciation rates used as dependent variables and the lagged appreciation rates included as independent variables. Specifically, we estimate regressions where the dependent variable is the appreciation rate measured from quarter t to $t+4$ and the appreciate rates used as the independent variables are measured from quarter $t-5$ to quarter $t-1$, from quarter $t-9$ to quarter $t-5$, and from quarter $t-13$ to quarter $t-9$, respectively.

In addition to the housing price series, we need proxies for the serial correlation of the demand shock and supply rigidity for each MSA, and other control variables that might be related to the property appreciation rate of MSAs. Specifically, we use the employment growth rate and the population growth rate, provided by Moody's Economy.com, as proxies for the growth in housing demand. The growth rate of the housing supply for each MSA is measured as the ratio of the number of new single-family housing starts to the total number of households, which we obtain from the Bureau of Census.

We use two measures to represent the short-run supply rigidity of MSAs. The first is the Wharton Residential Land Use Regulatory Index (WRLURI, and here after "regulation index") used in Gyourko, Saiz and Summers (2008) to capture the intensity of local growth control policies.[12] A high index value means that the MSA has zoning regulations or project approval practices that constrain new residential developments. The second proxy for the short-run supply rigidity is population density, since it tends to be more difficult to develop a project in a denser area. This is true because finding suitable land, obtaining building permits and preparing the site for development are more difficult and time consuming in a denser area. We measure an MSA's density as its population divided by the square miles of land area, where the land area size is reported in the 2000 Census Survey (by the Bureau of Census). As in Saiz (2010) we adjust the area for the amount of water in the MSA, however, we do not try to come up with a proxy for unbuildable land.

As an indication of the validity of the above supply rigidity measures we estimate the relation between supply rigidity and price levels. In theory, prices should be higher when the option to build additional housing units is more limited. Indeed, in unreported regressions we show that prices in cities that are denser or more restricted tend to be higher. It should also be noted that unreported regressions that use the median housing price level in a city as a proxy for supply rigidity generate similar results as the other two measures of supply rigidity. In particular, cities with higher housing prices exhibit greater serial correlation at yearly intervals.

Finally, we use the growth rate of the gross metropolitan product (GMP, obtained from the Bureau of Economic Analysis) to control for contemporaneous demand shocks.[13]

3.3. Sample description

Before proceeding, it is interesting to get a broad picture of the characteristics of regions that realized the highest price appreciation and population growth over our sample period. To do so, we sort our data of 97 MSAs and report the top-10 MSAs in terms of housing appreciation and population growth for each of the following periods: 1980-1989, 1990-1999, 2000-2006, and 2007-2011. As reported in Exhibit 1, for the most part, the MSAs that experienced the highest price appreciation were in relatively dense urban areas with relatively good weather. The evidence in Exhibit 1 also reveals that most of the cities that experienced the fastest population growth were in areas with relatively good weather and relatively low densities. The evidence of an interaction between good weather and density as determinants of population growth and price increases is broadly consistent with the existence of a demand shock over this time period, associated with a change in preferences for good weather, as discussed in studies by Rappaport (2007) and others, and the effect of supply rigidities associated with higher density on both prices and population. In other words, speaking very broadly, the interaction between supply rigidities and demand shocks, which is central to our model, seems to have some bite.

Insert Exhibit 1 Here

We next examine how the time series patterns in appreciation rates and housing supply growth are associated with our two measures of supply rigidities. We do this by looking at four different periods with different levels of demand growth. For each period, we stratify areas into three supply-rigidity-level groups (high, medium and low) based on our two short-run supply-rigidity proxies: population density and the regulation index,[14] and report each MSA's housing appreciation rate (the FHFA HPI index change) and its growth in housing supply (new single-family housing starts divided by the number of households).

Insert Exhibit 2 Here

Exhibit 2 reports each subsample's mean for each variable. When interpreting these numbers, it should be noted that in the 1983 to 1989 period and the 2000 to 2006 period there was substantial appreciation in housing prices, and in these periods, the more constrained MSAs (denser and more regulated) tended to appreciate more. In the 1990s, when appreciation rates were relatively low, and the post-2006 period, when prices fell, the cross-MSA relation between constraints and appreciation rates is pretty weak. It should also be noted that our density measure is a good predictor of both MSA population and price growth rates; denser areas experienced greater price increases and less population increase. However, the relation between the regulation index and the growth rates are pretty weak, suggesting that the regulations may slow down growth, but may not have a long run effect.

4. Assumption Validation and Empirical Results

As described earlier, our model assumes that the housing demand shock, as shown in Equation (2), is serially correlated, and the growth in housing supply is a function of past property appreciation rates, as shown in Equation (3). As we will show in this section, these patterns are indeed consistent with our data.

4.1. Serial correlation of demand shocks

We estimate the serial correlation of demand shocks in two ways. We first estimate a series of cross-sectional regressions of demand changes (i.e., employment and population growth) on their lagged values (up to three lags), and use the Fama-MacBeth procedure with the Newey-West adjustment to estimate standard errors. These estimates implicitly assume that the serial correlation is equal across cities. We then directly estimate serial correlation with time-series regressions for each city to gauge the degree to which these serial correlations differ.

Insert Exhibit 3 Here

The Fama-MacBeth regressions, reported in Exhibit 3, provide evidence of positive serial correlation in both demand shock proxies. For both employment and population growth, the first lagged term is positive and extremely significant, with the pattern more prominent before 2007 than after 2007. The second lagged term is significant for employment growth before 2007, but is not significant for population growth.

We next explore the cross-sectional patterns of the time-series correlation of the housing demand growth rate at the MSA level. Based on the preceding results, which shows that most of the serial correlation is captured by the first lag, we estimate the serial correlation over one year intervals for each of the 97 MSAs in our sample. In unreported regressions we find that in the full sample period, the serial correlation of employment growth is significantly positive in 91% of the MSAs and the serial correlation of population growth is significantly positive in 99% of the MSAs.

We also examine cross-sectional differences in serial correlations. Our analysis of these differences is partly motivated by concerns about the endogeniety of these demand shock proxies. In particular, it might be the case that the growth in employment and population is constrained by the ability of an MSA to absorb new residents. If this is the case, then we might expect growth rates to be less persistent in cities that are denser and have more supply rigidities. In fact, we find that growth persistence is stronger in cities with greater population density and more regulation, which is inconsistent with the idea that rigidities mitigate persistence.

It is possible that the reason why growth is more persistent in denser cities is that denser cities tend to be larger, and the growth in the demand for housing may be more persistent in larger cities. As we mentioned in the introduction, persistence in demand shocks can arise if innovations in one sector of a city spill over and create success in other sectors.[15] In addition, as discussed in Lamont and Stein (1999), an increase in real estate prices in a given city reduces the borrowing constraints of existing homeowners, thereby increasing their demand for housing. Moreover, as discussed by Chaney, Sraer and Thesmar (2012), increases in real estate prices can also reduce the financial constraints of the businesses in a city, increasing their investment expenditures, which might in turn positively influence the demand for housing.

It is likely that the above mentioned spillovers between various industry sectors and those between the real estate sector and industry are more important in larger cities. If this is indeed the case, we should expect to see more serial correlation in the factors that drive demand in larger cities. To test this we examine the relation between the magnitude of a city's GMP and the persistence of their demand growth rates. To do this, we estimate the following regression using the Fama-MacBeth procedure with the Newey-West adjustment:

$$d_{j,t} = \kappa_X + \upsilon_{X1} d_{j,t-1} + \upsilon_{X2} d_{j,t-2} + \upsilon_{X3} d_{j,t-3} + \varphi X_t + \zeta_{X1}\left[d_{j,t-1} X_t\right]$$

$$+\zeta_{X2}\left[d_{j,t-2} X_t\right] + \zeta_{X3}\left[d_{j,t-3} X_t\right] + \varepsilon_{Xt}, \qquad (11)$$

where *j* is the MSA index, *t* is the quarter index, $d_{j,t}$ is the annual demand growth rate at year t for MSA j and is the serially overlapping year-on-year growth rate calculated for each quarter, $d_{j,t-i}$

is the i-year lagged annual demand growth rate, X_t is a GMP size, $[d_{j,t-i}X_t]$ is the interaction between the i-year lagged demand growth rate and the GMP size, κ_X is a constant and ε_{Xt} is the error term.

Insert Exhibit 4 Here

Exhibit 4 reports the results. Panel A uses the employment growth rate as the proxy for the demand growth and Panel B uses the population growth rate as the proxy for demand growth. In both cases we find that demand growth rates tend to be very persistent. When employment growth is used as the demand proxy we find that both the one year and the two year lagged growth rate explains the current growth rate. When population growth is used as the demand proxy the first lag is very significant, but the second lag is not reliably different than zero. In both cases, the estimated interaction terms indicate that persistence is stronger in larger cities, when the growth rate is lagged by one year, but the coefficient of the interaction of size with the second year lag is negative, but smaller and less significant. These patterns hold in the entire sample period and the pre-2007 period. In the post-2007 period, the results are consistent, but because of the short sample period the coefficients tend to be statistically less significant.

4.2. Supply responses to price changes

We now turn our attention to the assumed link between housing supply growth rates and lagged property appreciation rates. Specifically, we regress housing supply growth rates (new housing start/number of households) on three lagged values of the property appreciation rate. We do this by running cross-sectional regressions in each quarter of the housing supply growth rate over the past four quarters on the appreciation rate in previous years. Again, we report the mean of the coefficient estimates and their standard errors using the Fama-MacBeth procedure with Newey-West standard errors.

Insert Exhibit 5 Here

The estimates of this regression are reported in Exhibit 5. These regression estimates indicate that before the 2007 crisis, supply responds significantly to the appreciation rate in the previous year, but the appreciation rate at a longer lag does not have a material effect on supply. Consistent with the lower supply elasticity during downturns we find evidence of a weaker supply response in the post 2007 period. However, given the shorter post-2007 sample period we have very little power to detect differences between the pre- and post-crisis periods.

To understand cross city differences in supply responses we consider the two measures of supply rigidity that we described in Section 3.2, the Wharton Residential Land Use Regulatory Index (WRURI) and population density. We hypothesize that MSAs with more regulation or greater density will have a lower response to past price changes. To test this hypothesis, we estimate the following regression of the supply growth rate on past price changes, the rigidity measure, and their interaction terms:

$$s_{j,t} = \kappa_Y + \upsilon_{Y1} r_{j,t-1} + \upsilon_{Y2} r_{j,t-2} + \upsilon_{Y3} r_{j,t-3} + \varphi Y_t + \zeta_{Y1}\left[r_{j,t-1} Y_t\right]$$

$$+\zeta_{Y2}\left[r_{j,t-2} Y_t\right] + \zeta_{Y3}\left[r_{j,t-3} Y_t\right] + \varepsilon_{Yt}, \qquad (12)$$

where *j* is the MSA index, *t* is the quarter index, $s_{j,t}$ is the annual supply growth rate at year t (here we use serially overlapping year-on-year growth rate calculated at each quarter), $r_{j,t-i}$ is the *i*-year lagged annual property appreciation rate, Y_t is the proxy for supply rigidity (either the regulatory index or the population density), $\left[r_{j,t-i} Y_t\right]$ is the interaction between the i-year lagged property appreciation rate and the proxy for the supply rigidity, κ_Y is a constant and ε_{Yt} is the error term. Again, we use the Fama-MacBeth procedure with the Newey-West adjustment to estimate the regression.

Insert Exhibit 6 Here

Exhibit 6 reports the results, with Panel A reporting estimates using the population density as the proxy for supply rigidities and Panel B reporting estimates using the regulatory index to measure rigidities. As we expect, in the pre-2007 period, the regression estimates indicate that MSAs tend to add more housing supply in cities with weaker supply rigidities.[16] Moreover, for both proxies, the coefficients of the interaction variables indicate that supply responds more to past price changes in MSAs with less supply rigidity, suggesting that our supply rigidity measure are indeed good proxies for supply elasticities. Finally, it should be noted that the results are quite weak after 2007, which is consistent with very weak supply elasticities during downturns.

5. Housing Price Patterns

As we show in Proposition 1, under certain conditions, property appreciation rates are positively serially correlated over relatively short intervals, followed by a partial reversal. Those conditions, i.e., serially correlated demand growth and rigid supply, were examined in the last section. In this section we directly examine the time series pattern of housing appreciation rates.

Exhibit 7 reports regressions of the annual appreciation rates on lagged annual appreciation rates (with and without additional control variables) for our panel data of 97 MSAs, using the Fama-MacBeth procedure with the Newey-West adjustment. Panel A reports the result when only the lagged terms are used. Panel B reports the results when we include an additional control variable for the change in the gross metro product. These Panels are further divided into Columns I and II, which estimate regressions both with and without a gap between the measurement intervals used for the dependent and independent variables. In Column I there is no gap between the measurement intervals used for the dependent and independent variables. In Column II there is a one quarter gap between the measurement of the appreciation rates used in the dependent and independent variables to correct for serially correlations that may be generated because of stale prices.

In each of the regressions we find that the property appreciation rate is reliably positively correlated with the price change in the previous year but is negatively correlated with the price change 3 years earlier. As we show in the table, the sum of the three lagged coefficients is significantly positive, which indicates that the lagged price change is only partially reversed. The one year serial correlation is only slightly weaker after 2007 and evidence of a reversal in the subsequent years is even stronger in the post-2007 period.

Given the short sample period, we are hesitant to draw strong conclusions from the post-2007 sample period. However, the strong evidence of reversals in a time period with weak supply responses is of interest since it is inconsistent with our model. One possible explanation is that although price declines do not lead to a significant decline in the actual housing stock, because of either debt overhang or loss aversion (as discussed in Genesove and Mayer (2001)), a price decline can temporarily reduce the available supply of housing that are on the market, which can have the same effect on housing prices as a reduction in the actual housing stock.

Insert Exhibit 7 Here

We now explore the determinants of cross-city differences in these price movement patterns. Specifically, we explore the implications of our model, which suggests that price change patterns are influenced by the degree of demand persistence and supply rigidities. To start the analyses, we run the regression in Equation (8) for the same panel data of 97 MSAs we used for the regression reported in Panel B of Exhibit 7, except that we now add proxies for demand persistence and supply rigidities and interactions of these proxies with the three lagged property appreciation rates. Specifically, we use "GMPsize", the natural logarithm of Gross Metropolitan Product, as a proxy for the serial correlation of the demand shock. We also use "popuden", the population density, and "regindx", the regulation index, as proxies for supply rigidity.

Exhibit 8, which reports these regressions, contains two columns that include independent variables that are not lagged (Column I), and independent variables that are lagged by one quarter (Column II), and three different Panels. Panel A in Exhibit 8 reports the results using GMP size as a proxy for the demand serial correlation and Panel B and C report the results using population density and regulation index as proxies for supply rigidity.

Insert Exhibit 8 Here

In all three panels, for the full sample and the before-2007 subsample, the coefficients of the terms that interact the proxy variable and the 1-year lagged appreciation rate are positive, indicating that an MSA with stronger short-run serial correlation in the growth rate of demand (proxied by GMP size) or with a higher level of supply rigidity (proxied by either population density or regulation index) exhibit greater positive first order serial correlation in property appreciation rates. These coefficients are statistically significant in the regressions reported in Column I, but are a bit lower in magnitude in the regressions reported in Column II, and are not significantly different than zero in regressions with the interactions involving GMP size and density. In the after-2007 sample, none of the proxy variables affects the 1-year serial correlation in appreciation rates.

The evidence suggests that although larger and denser cities exhibit stronger first order serial correlation, the subsequent reversal effect is not reliably related to either size or density. However, this is not the case when we measure rigidity with the regulation index. The more regulated markets do exhibit greater first order serial correlation, but the effect of regulation on appreciation rate persistence is reversed after one year, suggesting that the regulation does not have a permanent effect.

6. Conclusions

There are a number of applications in corporate finance that require assumptions about the price process of a real asset. For example, to value a financial asset, like a debt instrument, whose value is contingent on the value of real assets, (e.g., project debt that is collateralized by a power plant), one needs to make assumptions about the process generating the value of the underlying asset. This is also the case when we consider real options with values that are contingent on the values of other real assets, e.g., the option to expand a manufacturing facility.

In most cases, we apply the type of analysis that is used to value derivatives on financial assets and assume that prices of the underlying real asset can be approximated by a random walk. However, as we illustrate with our simple reduced form model, price changes of real assets can exhibit positive serial correlation over relatively short intervals and may exhibit negative serial correlation over longer intervals. The key assumptions that generate these results are serial correlation of demand shocks and supply rigidities, and financial frictions that tend to make investors myopic. These assumptions, which we think apply to a wide range of real asset markets, clearly apply to the U.S. housing market. Indeed, as our empirical tests confirm, housing price changes in most cities exhibit positive serial correlation over yearly intervals and subsequent reversals. Moreover, as our model suggests, there can be significant differences in the serial correlation of housing price changes in cities with different characteristics as well as at different stages of the housing market cycle.

Our analysis is directly applicable to the valuation of mortgages and other contracts that are contingent on the value of owner occupied housing. A question, which we will leave to future research, is the extent to which our analysis can be applied to the price process of real assets that are held in the corporate sector.

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Acknowledgement

We acknowledge the helpful comments from Su Han Chan, Sing Tien Foo, David Frame, Richard Gil, Christopher Parsons and seminar participants at Chinese Academy of Sciences, Chinese Academy of Social Sciences, Colorado State University, Johns Hopkins University, Massey University, Shanghai University of Finance and Economics, 2009 AREUEA/AsRES Joint Meeting and 2010 GCREC Annual Meeting. We thank Jiajin Chen, Yalan Feng and Mariya Letdin for their research assistance on this paper.

Appendix A

Proof for Proposition 1:

Given that $D_0 = z_0 - bp_0$ and S_0 is exogenously determined, the market clearing condition guarantees that $z_0 - bp_0^* = S_0$. This means that $p_0^* = \frac{z_0 - S_0}{b}$. To simplify the model presentation, we define $m = 1 - \frac{S_0}{z_0} = \frac{b\, p_0^*}{z_0}$ and restrict $m \in [0,1)$ to ensure that the initial demand $D_0 = z_0 - bp_0 = (1-m)z_0$ is non-negative. In addition, we define the demand shock change rate at time t as $e_t = \frac{z_t - z_{t-1}}{z_{t-1}}$, that is, $z_t = z_{t-1}(1+e_t)$. Finally, we ignore the zero-mean error term in Equation (2) by assuming $\sigma_t = 0$. To simply the model presentation, we do not consider the natural growth rate in supply (that is, the replacement of depreciated properties) by assuming $\delta_t = 0$.

Combining equations (1), (2) and (3) and applying the market clearing condition to the four-date model framework, we derive

$$D_0 = z_0 - bp_0,\ \ S_0 = S_0 \ and\ \ p_0^* = \frac{z_0 - S_0}{b} = \frac{z_0 m}{b}; \tag{13}$$

$$D_1 = z_1 - bp_1,\ \ S_1 = S_0 \ \ and\ \ p_1^* = \frac{z_0}{b}(e_1 + m); \tag{14}$$

$$D_2 = z_2 - bp_2,\ \ S_2 = S_1\left[1 + \frac{1}{k_1}\left(\frac{p_1 - p_0}{p_0}\right)\right]$$

$$and\ \ p_2^* = \frac{z_0}{bk_1 m}\{k_1 m^2 + e_1^2 k_1 m x_1 + e_1[m(1 + k_1 + k_1 x_1) - 1]\}; \tag{15}$$

$$D_3 = z_3 - bp_3,\ \ S_3 = S_2\left[1 + \frac{1}{k_1}\left(\frac{p_2 - p_1}{p_1}\right) + \frac{1}{k_2}\left(\frac{p_1 - p_0}{p_0}\right)\right]$$

$$and\ \ p_3^* = \frac{z_0}{b}\{(1+e_1)(1+e_1x_1)(1+e_1x_1^2) - (1-m)\left(1+\frac{e_1}{k_1m}\right)\cdot$$

$$\left[1+\frac{e_1}{k_2m}+\frac{e_1(m(1+(1+e_1)k_1x_1)-1)}{k_1^2m(m+e_1)}\right]\}. \quad (16)$$

To explore the time-series properties of property appreciation rate, the change rate of the equilibrium price is written as a weighted average of historical appreciation rates plus an error term, or

$$\frac{p_t^*-p_{t-1}^*}{p_{t-1}^*} = \sum_{i=1}^{t-1} a_i\left(\frac{p_{t-i}^*-p_{t-i-1}^*}{p_{t-i-1}^*}\right)+\varepsilon_t, \quad (17)$$

where a_i measures the sensitivity of current appreciation rate to the i-th period lagged appreciation rate. ε_t is a zero-mean error term.

It is important to note that the significance level and the sign of a_i in Equation (17) can be used to judge the serial correlation patterns in the price dynamics. In the four-date framework, we assume that the market is in a stable condition at time 0 so that $p_0^* = p_{-1}^*$. Equation (17) can be re-written as

$$\frac{p_2^*-p_1^*}{p_1^*} = a_1\left(\frac{p_1^*-p_0^*}{p_0^*}\right)+\varepsilon_2 \text{ and} \quad (18)$$

$$\frac{p_3^*-p_2^*}{p_2^*} = a_1\left(\frac{p_2^*-p_1^*}{p_1^*}\right)+a_2\left(\frac{p_1^*-p_0^*}{p_0^*}\right)+\varepsilon_3. \quad (19)$$

Ignoring the error terms ε_2 and ε_3 and substituting the equilibrium prices expressed in Equations (13), (14), (15) and (16) into Equations (18) and (19), the two serial correlation coefficients, a_1 and a_2, can be expressed as

$$a_1 = \frac{-1+m[1+(1+e_1)k_1x_1]}{k_1(m+e_1)} > 0\ \left(\text{when}\ \ k_1x_1 > \frac{1-m}{m(1+e_1)} = \frac{(z_0-bp_0)z_0}{bp_0z_1}\right), \quad (20)$$

$$a_2 = \frac{m}{e_1}\left[\frac{p_3^* - p_2^*}{p_2^*} - \frac{e_1 a_1^2}{m}\right] < 0 \quad \left(\text{when} \quad \frac{p_3^* - p_2^*}{p_2^*} < \frac{e_1 a_1^2}{m} = \frac{(z_1 - z_0)a_1^2}{bp_0}\right), \tag{21}$$

This means that, with the conditions specified in Equations (20) and (21), the appreciation rate of current period is positively correlated with the appreciation rate in the previous period, but is negatively correlated with the appreciation rate two periods ago. The comparative static analyses on a_1 and a_2 generate

$$\frac{\partial a_1}{\partial x_1} = \frac{m(1+e_1)}{m+e_1} > 0, \tag{22}$$

$$\frac{\partial a_1}{\partial k_1} = \frac{1-m}{(m+e_1)k_1^2} > 0, \tag{23}$$

$$\frac{\partial a_2}{\partial y_2} = \frac{\partial a_2}{\partial k_2} \cdot \frac{\partial k_2}{\partial y_2} = -k_2^2 \frac{\partial a_2}{\partial k_2} \quad \left(\text{given } k_2 = \frac{1}{y_2},\ \frac{\partial k_2}{\partial y_2} = -\frac{1}{y_2^2} = -k_2^2\right)$$

$$= -\frac{(1-m)(e_1 + k_1 m)}{\left[k_1 m^2 + e_1^2 k_1 m x_1 + e_1\left(-1 + m(1 + k_1 + k_1 x_1)\right)\right]}$$

$$= -\frac{z_0(1-m)(e_1 + k_1 m)}{bp_2 m k_1} < 0. \tag{24}$$

■Q.E.D.

EXHIBIT 1

MSA Ranking Based on Property Appreciation Rate and Population Growth Rate by Period

MSA name	State	Annualized housing appreciation rate	Average population (000)	Average GMP (mil. $)	Year 2000 population density (per square mile)	MSA name	State	Annualized housing appreciation rate	Average population (000)	Average GMP (mil. $)	Year 2000 population density (per square mile)
Top 10 MSAs by property appreciation rate						Top 10 MSAs by population growth rate					
[1980-1989]						[1980-1989]					
Nassau-Suffolk	NY	14.30%	2620.00	43.50	2300.00	Riverside-San Bernardino-Ontario	CA	5.16%	1930.00	22.90	119
Boston-Quincy	MA	13.00%	1700.00	40.90	1030.00	Las Vegas-Paradise	NV	4.68%	568.00	10.10	39.7
Springfield	MA	12.00%	652.00	9.69	805.00	Orlando-Kissimmee	FL	4.25%	987.00	17.20	471.00
New York-White Plains-Wayne	NY	11.90%	10300.00	239.00	8160	Austin-Round Rock	TX	3.77%	725.00	12.20	296.00
New Haven-Milford	CT	11.10%	782.00	14.80	1260	Phoenix-Mesa-Scottsdale	AZ	3.49%	1910.00	32.10	223.00
Providence-New Bedford-Fall River	RI	10.60%	1460.00	21.50	1040	San Luis Obispo-Paso Robles	CA	3.46%	184.00	2.75	74.70
Newark-Union	NJ	10.60%	1980.00	41.40	1290.00	Fort Worth-Arlington	TX	3.20%	1190.00	19.10	584
San Jose-Sunnyvale-Santa Clara	CA	10.50%	1430.00	33.60	1300.00	Sacramento--Arden-Arcade--Roseville	CA	3.07%	1250.00	22.00	399
San Francisco-San Mateo-Redwood City	CA	10.40%	1550.00	45.70	1700.00	Raleigh-Cary	NC	3.03%	462.00	6.64	341.00
San Luis Obispo-Paso Robles	CA	10.30%	184.00	2.75	74.70	Bakersfield	CA	3.01%	468.00	8.32	81.3
Sample Median		4.32%	831.00	14.80	444.00	Sample Median		1.06%	831.00	14.80	444.00
[1990-1999]						[1990-1999]					
Salt Lake City	UT	8.01%	876.58	25.51	824.70	Las Vegas-Paradise	NV	6.43%	1026.97	30.26	39.7
Portland-Vancouver-Beaverton	OR	7.80%	1734.23	49.61	381.50	Austin-Round Rock	TX	3.95%	1021.26	29.51	295.90
Denver-Aurora	CO	7.35%	1913.10	62.13	560.90	Raleigh-Cary	NC	3.91%	659.74	17.28	340.5
Salem	OR	7.09%	314.06	6.24	180.40	Phoenix-Mesa-Scottsdale	AZ	3.82%	2701.69	73.92	223.10
Austin-Round Rock	TX	5.87%	1021.26	29.51	295.90	Boise City-Nampa	ID	3.82%	388.68	9.48	262.9
Colorado Springs	CO	5.78%	474.04	11.49	243.10	Atlanta-Sandy Springs-Marietta	GA	3.29%	3600.44	116.21	671.5
Tacoma	WA	5.36%	643.91	14.06	417.40	Orlando-Kissimmee	FL	2.98%	1424.02	41.43	471.1
Davenport-Moline-Rock Island	IA	5.25%	373.94	10.15	210.20	Reno-Sparks	NV	2.92%	297.66	10.06	53.5
Boise City-Nampa	ID	5.24%	388.68	9.48	262.90	Dallas-Plano-Irving	TX	2.78%	2987.23	104.19	568.90
Ann Arbor	MI	5.18%	299.21	10.90	285.30	Colorado Springs	CO	2.76%	474.04	11.49	243.10
Sample Median		3.28%	1023.96	29.51	444.00	Sample Median		1.25%	1023.96	29.51	444.00
[2000-2006]						[2000-2006]					
Miami-Miami Beach-Kendall	FL	16.33%	2346.10	85.28	1157.90	Las Vegas-Paradise	NV	4.50%	1609.76	66.40	39.7
Riverside-San Bernardino-Ontario	CA	16.02%	3641.90	102.57	119.40	Raleigh-Cary	NC	3.64%	895.30	35.85	340.5
Fort Lauderdale-Pompano Beach-Deerfield Beach	FL	15.93%	1704.44	60.60	1346.50	Boise City-Nampa	ID	3.42%	519.20	18.15	262.9
Merced	CA	15.76%	231.11	5.67	109.20	Orlando-Kissimmee	FL	3.30%	1839.19	76.77	471.10
Los Angeles-Long Beach-Glendale	CA	15.65%	9710.72	424.90	2344.20	Austin-Round Rock	TX	3.26%	1393.28	56.08	295.90
Bakersfield	CA	15.63%	720.97	24.90	81.3	Riverside-San Bernardino-Ontario	CA	3.23%	3641.90	102.57	119.40
Fresno	CA	15.34%	845.06	30.04	113.90	Phoenix-Mesa-Scottsdale	AZ	3.01%	3581.80	140.69	223.1
Santa Ana-Anaheim-Irvine	CA	14.71%	2914.20	160.05	3605.60	Charlotte-Gastonia-Concord	NC	2.94%	1454.02	70.21	444
Santa Barbara-Santa Maria-Goleta	CA	14.06%	405.12	17.58	145.90	Bakersfield	CA	2.73%	720.97	24.90	81.30
Washington-Arlington-Alexandria	DC	14.01%	3967.59	220.34	756.30	Reno-Sparks	NV	2.66%	377.02	17.48	53.5
Sample Median		7.33%	1137.27	48.32	444.00	Sample Median		1.00%	1137.27	48.32	444.00
[2007-2011]						[2007-2011]					
Kennewick-Pasco-Richland	WA	1.63%	244.82	10.88	65.10	Raleigh-Cary	NC	3.26%	1113.92	52.91	340.5
Austin-Round Rock	TX	1.26%	1695.17	79.57	295.90	Austin-Round Rock	TX	3.12%	1695.17	79.57	295.90
Buffalo-Niagara Falls	NY	1.23%	1134.57	62.51	746.60	Kennewick-Pasco-Richland	WA	2.85%	244.82	10.88	65.1
Pittsburgh	PA	1.22%	2354.07	113.38	509.90	New Orleans-Metairie-Kenner	LA	2.36%	1145.83	59.63	393.50
Houston-Sugar Land-Baytown	TX	1.11%	5864.39	343.68	705.70	Charlotte-Gastonia-Concord	NC	2.31%	1741.16	90.88	444
Rochester	NY	0.87%	1055.07	58.21	320.60	San Antonio	TX	2.28%	2108.85	83.47	478.7
Davenport-Moline-Rock Island	IA	0.64%	377.55	18.06	210.20	Houston-Sugar Land-Baytown	TX	2.18%	5864.39	343.68	705.7
Oklahoma City	OK	0.52%	1236.28	53.42	255.10	Fort Worth-Arlington	TX	2.15%	2117.08	89.34	583.5
Beaumont-Port Arthur	TX	0.51%	386.07	21.84	178.80	Phoenix-Mesa-Scottsdale	AZ	2.10%	4190.09	184.69	223.10
Syracuse	NY	0.43%	660.10	36.56	237.50	Dallas-Plano-Irving	TX	2.00%	4198.27	232.12	568.90
Sample Median		-3.43%	1134.57	59.81	444.00	Sample Median		1.01%	1134.57	59.81	444.00

This table lists the top 10 MSAs in our sample that have the highest property appreciation rate (measured by the FHFA HPI growth rate) or population growth rate during the 1980-1989, 1990-1999, 2000 -2006 and 2007-2011 periods. For each period, we calculate the annualized growth rate of FHFA HPI index and population growth rate. We sort the 97 MSAs based on these two criteria and report the top 10 in each category for each of the four periods. The table also reports the average population, average GMP, and the year 2000 population density (offered by the Census) of each of these MSAs during the period.

EXHIBIT 2

Property Appreciation Rates and Housing Supply Categorized by Period and by Supply Rigidity

	Level of Supply Rigidity	Annualized Appreciation Rate	Annualized housing start/ household number
[1] 1983-1989: grouping based on 1983 Q1 population density		Mean	Mean
	Low	0.031	0.082
	Medium	0.040	0.081
	High	0.086	0.056
	High-Low	0.055***	-0.025***
[2] 1990-1999: grouping based on 1990 Q1 population density			
	Low	0.048	0.091
	Medium	0.052	0.084
	High	0.029	0.051
	High-Low	-0.019***	-0.040***
[3] 2000-2006: grouping based on 2000 Q1 population density			
	Low	0.079	0.072
	Medium	0.060	0.066
	High	0.098	0.041
	High-Low	0.018**	-0.031***
[4] 2007-2011: grouping based on 2007 Q1 population density			
	Low	-0.037	0.021
	Medium	-0.022	0.023
	High	-0.030	0.013
	High-Low	0.007	-0.008***
[5] 1983-2011: grouping based on 1983 Q1 population density			
	Low	0.030	0.066
	Medium	0.033	0.062
	High	0.045	0.040
	High-Low	0.015*	-0.026**
[6] 1983-1989: grouping based on WRLURI regulation index			
	Low	0.040	0.063
	Medium	0.049	0.078
	High	0.069	0.077
	High-Low	0.030***	0.013*
[7] 1990-1999: grouping based on WRLURI regulation index			
	Low	0.046	0.075
	Medium	0.048	0.080
	High	0.036	0.070
	High-Low	-0.010*	-0.005
[8] 2000-2006: grouping based on WRLURI regulation index			
	Low	0.056	0.057
	Medium	0.081	0.062
	High	0.099	0.059
	High-Low	0.043***	0.002
[9] 2007-2011: grouping based on WRLURI regulation index			
	Low	-0.015	0.021
	Medium	-0.035	0.019
	High	-0.039	0.018
	High-Low	-0.024***	-0.003
[10] 1983-2011: grouping based on WRLURI regulation			
	Low	0.032	0.053
	Medium	0.035	0.059
	High	0.041	0.055
	High-Low	0.009	0.002

This table displays property appreciation rates and the housing supply of areas categorized by measures of supply rigidity for the 1983-1989, 1990-1999, 2000-2006, 2007-2011, and 1983-2011 periods. For each period, we stratify MSAs into three groups based on the level of supply rigidity (high, medium and low) proxied by population density at the beginning of the period or by the WRLURI regulation index. Population density is the ratio of population and the 2000 land area and WRLURI regulation index is the Wharton Residential Land Use Regulatory Index estimated by Gyourko, Saiz and Summers (2008). For the difference between the “high” and “low” subsamples, ***, ** and * indicate significance at the 1% level, 5% level and 10% level, respectively.

EXHIBIT 3
Serial Correlations in Demand Growth Rates

Panel A: The demand growth rate is measured by the employment change rate

Variable	Employment		
	Full Sample	Before 2007	After 2007
Intercept	0.005*	0.008***	-0.006
Employment(-1)	0.468***	0.485***	0.384**
Employment(-2)	0.105***	0.111***	0.079
Employment(-3)	0.011	0.033	-0.094
Number of observations	11252	9312	1940
[Joint test]			
Employment(-1)+(-2)+(-3)	0.584***	0.629***	0.370***
Employment(-2)+(-3)	0.116***	0.144***	-0.014

Panel B: The demand growth rate is measured by the population change rate

Variable	Population		
	Full Sample	Before 2007	After 2007
Intercept	0.001**	0.001	0.002**
Population(-1)	0.836***	0.868***	0.682***
Population(-2)	0.065	0.061	0.085
Population(-3)	0.021	0.021	0.019
Number of observations	11252	9312	1940
[Joint test]			
Population(-1)+(-2)+(-3)	0.922***	0.950***	0.786***
Population(-2)+(-3)	0.086	0.082	0.104

This table shows the serial correlations in demand growth rates. The dependent variable is the employment growth rate (denoted as "Employment") or the population growth rate (denoted as "Population"). The independent variables are the 1-year, 2-year and 3-year lagged terms of the dependent variable. Joint tests report the significance levels of combined selected lagged terms. Results are estimated from Fama-MacBeth regressions with Newey-West adjustments. ***, ** and * indicate significance at the 1% level, 5% level and 10% level, respectively

EXHIBIT 4

The Effects of MSA Size on the Serial Correlation of Demand Growth Rates

Panel A: Demand growth rate proxied by employment growth rate

Variable	Employment		
	Full Sample	Before 2007	After 2007
Intercept	0.013***	0.017***	-0.008
Employment(-1)	0.150***	0.163**	0.084
Employment(-2)	0.265***	0.244***	0.361
Employment(-3)	-0.064	-0.073	-0.023
GMPsize	-0.002***	-0.003***	0.001
GMPsize * Employment(-1)	0.104***	0.108***	0.084*
GMPsize * Employment(-2)	-0.055**	-0.051**	-0.074
GMPsize * Employment(-3)	0.026	0.036	-0.019
Number of observations	11252	9312	1940
[Joint test]			
Employment(-1)+(-2)	0.414***	0.408***	0.445
Employment(-1)+(-2)+(-3)	0.350***	0.335***	0.422**
Employment(-2)+(-3)	0.201***	0.172**	0.339
GMPsize * (Employment(-1)+(-2))	0.049*	0.057*	0.010
GMPsize * (Employment(-1)+(-2)+(-3))	0.075***	0.093***	-0.009
GMPsize * (Employment(-2)+(-3))	-0.029	-0.015	-0.093

Panel B: Demand growth rate proxied by population growth rate

Variable	Population		
	Full Sample	Before 2007	After 2007
Intercept	0.002***	0.002**	0.002*
Population(-1)	0.580***	0.604***	0.465**
Population(-2)	0.162	0.154	0.203
Population(-3)	0.105	0.109	0.086
GMPsize	0.000**	0.000**	0.000
GMPsize * Population(-1)	0.088***	0.092**	0.065*
GMPsize * Population(-2)	-0.049	-0.052	-0.036
GMPsize * Population(-3)	-0.014	-0.013	-0.019
Number of observations	11252	9312	1940
[Joint test]			
Population(-1)+(-2)	0.742***	0.758***	0.668**
Population(-1)+(-2)+(-3)	0.847***	0.867***	0.754***
Population(-2)+(-3)	0.267**	0.263**	0.289**
GMPsize * (Population(-1)+(-2))	0.039	0.040	0.029
GMPsize * (Population(-1)+(-2)+(-3))	0.025**	0.027***	0.010
GMPsize * (Population(-2)+(-3))	-0.063*	-0.065	-0.055

This table examines the relation between MSA size and the magnitude of serial correlation in the demand growth rate. Demand is measured as the employment growth rate (denoted as "Employment") or the population growth rate (denoted as "Population"). The independent variables include the 1-year, 2-year and 3-year lagged terms of the dependent variable, and their interactions with GMPsize. GMPsize is the MSA size measured using the panel data of the natural logarithm of GMP (Gross Metropolitan Product). Joint tests report the significance levels of combined selected lagged terms. Results are estimated from Fama-MacBeth regressions with Newey-West adjustments. ***, ** and * indicate significance at the 1% level, 5% level and 10% level, respectively.

EXHIBIT 5

The Effect of Past Property Appreciation Rates on the Growth Rate of Housing Supply

Variable	Supply growth rate		
	Full Sample	Before 2007	After 2007
Intercept	15.615***	17.445***	6.833***
Return(-1)	25.638***	27.302***	17.654
Return(-2)	2.485	1.876	5.409
Return(-3)	8.201	9.190	3.454
Number of observations	11252	9312	1940
[Joint test]			
Return(-1)+(-2)+(-3)	36.324***	38.367***	26.517***
Return(-2)+(-3)	10.685	11.065	8.863

This table reports the effects of 1-year, 2-year and 3-year lagged property appreciation rates of the current supply growth rate. The dependent variable is the supply growth rate, proxied by the ratio of new single-family housing starts to the number of households. The property appreciation rate is measured by the FHFA HPI growth rate and is denoted as "Return". Joint tests report the significance levels of combined selected lagged terms. Results are estimated from Fama-MacBeth regressions with Newey-West adjustments. ***, ** and * indicate significance at the 1% level, 5% level and 10% level, respectively.

EXHIBIT 6

The Effects of Population Density or Regulation Index on the Supply Growth Rate

Panel A: Supply rigidity proxied by population density factor popuden”

Variable	Supply growth rate		
	Full Sample	Before 2007	After 2007
Intercept	16.121***	17.994***	7.130***
Return(-1)	51.967***	57.561***	25.120*
Return(-2)	1.751	1.586	2.540
Return(-3)	12.631	12.862	11.526
Popuden	-1.565***	-1.854***	-0.179
Popuden * Return(-1)	-45.372***	-53.974***	-4.082
Popuden * Return(-2)	7.773	9.674	-1.350
Popuden * Return(-3)	2.253	5.227	-12.024
Number of observations	11252	9312	1940
[Joint test]			
Return(-1)+(-2)	53.718***	59.147***	27.659**
Return(-1)+(-2)+(-3)	66.349***	72.008***	39.185***
Return(-2)+(-3)	14.382	14.448	14.065
Popuden * (Return(-1)+(-2))	-37.598**	-44.299**	-5.432
Popuden * (Return(-1)+(-2)+(-3))	-35.345**	-39.072**	-17.456
Popuden * (Return(-2)+(-3))	10.026	14.901	-13.374

Panel B : Supply rigidity proxied by regulation index “regindx”

Variable	Supply growth rate		
	Full Sample	Before 2007	After 2007
Intercept	15.822***	17.671***	6.946***
Return(-1)	26.440**	28.596**	16.094
Return(-2)	2.540	1.848	5.863
Return(-3)	5.821	6.114	4.416
Regindx	2.430***	2.676***	1.250***
Regindx * Return(-1)	-13.061*	-17.384**	7.691*
Regindx * Return(-2)	5.503	7.075	-2.042
Regindx * Return(-3)	5.496	7.718	-5.169
Number of observations	11252	9312	1940
[Joint test]			
Return(-1)+(-2)	28.980***	30.444**	21.957**
Return(-1)+(-2)+(-3)	34.801***	36.557**	26.373***
Return(-2)+(-3)	8.361	7.961	10.279
Regindx * (Return(-1)+(-2))	-7.558	-10.309	5.650
Regindx * (Return(-1)+(-2)+(-3))	-2.062	-2.591	0.481
Regindx * (Return(-2)+(-3))	10.999	14.793	-7.211

This table examines the relation between population density and the supply response to price changes. The dependent variable is the supply growth rate, proxied by the ratio of new single-family housing starts to the number of households. The property appreciation rate is measured by the FHFA HPI growth rate (denoted as “Return”). “Popuden” is the population density dummy, which is 1 if the population density (matched to the 2000 land area) of the MSA is at or higher than the median of the 97 MSAs in the sample in each year. “Regindx" is the Wharton Residential Land Use Regulatory Index estimated by Gyourko, Saiz and Summers (2008). The independent variables include the 1-year, 2-year and 3-year lagged terms of the property appreciation rate (Return), and their interactions with the proxies for supply rigidity. Joint tests report the significance levels of combined selected lagged terms. Results are estimated from Fama-MacBeth regressions with Newey-West adjustments. ***, ** and * indicate significance at the 1% level, 5% level and 10% level, respectively.

EXHIBIT 7

Serial Correlations in Property Appreciation Rate

Panel A: without control variables

Variable	[I] Return			Variable	[II] Return		
	Full Sample	Before 2007	After 2007		Full Sample	Before 2007	After 2007
Intercept	0.015***	0.018***	0.002	Intercept	0.018***	0.021***	0.005
Return(-1)	0.816***	0.831***	0.748***	Return(-1s)	0.780***	0.812***	0.623***
Return(-2)	-0.065	-0.029	-0.239**	Return(-2s)	-0.061	-0.024	-0.239**
Return(-3)	-0.128***	-0.132***	-0.110**	Return(-3s)	-0.170***	-0.171***	-0.165***
Number of observations	11252	9312	1940	Number of observations	11252	9312	1940
[Joint test]				[Joint test]			
Return(-1)+(-2)+(-3)	0.624***	0.671***	0.400***	Return(-1s)+(-2s)+(-3s)	0.548***	0.617***	0.219*
Return(-2)+(-3)	-0.193***	-0.160***	-0.348**	Return(-2s)+(-3s)	-0.232***	-0.196***	-0.404***

Panel B: with the concurrent gross metro product growth rate as a control variable

Variable	[I] Return			Variable	[II] Return		
	Full Sample	Before 2007	After 2007		Full Sample	Before 2007	After 2007
Intercept	-0.001	0.000	-0.006	Intercept	0.000	0.001	-0.005
Return(-1)	0.766***	0.775***	0.721***	Return(-1s)	0.721***	0.748***	0.590***
Return(-2)	-0.053	-0.016	-0.232	Return(-2s)	-0.043	-0.005	-0.229**
Return(-3)	-0.106***	-0.105***	-0.109**	Return(-3s)	-0.146***	-0.143***	-0.157***
Gross metro product	0.264***	0.275***	0.212***	Gross metro product	0.309***	0.319***	0.262**
Number of observations	11252	9312	1940	Number of observations	11252	9312	1940
[Joint test]				[Joint test]			
Return(-1)+(-2)+(-3)	0.607***	0.654***	0.380***	Return(-1s)+(-2s)+(-3s)	0.532***	0.600***	0.204*
Return(-2)+(-3)	-0.159***	-0.121**	-0.341**	Return(-2s)+(-3s)	-0.189***	-0.148***	-0.386***

This table reports the serial correlations of property appreciation rates. The property appreciation rate is measured by the FHFA HPI growth rate and is denoted as "Return". In a type [I] regression, the independent variables include 1-year, 2-year and 3-year lagged property appreciation rates. In a type [II] regression, the independent variables include 1-year, 2-year and 3-year lagged property appreciation rates that are further lagged by 1 quarter (therefore, the independent variables are essentially the 5-quarter, 9-quarter and 13-quarter lagged property appreciation rates). The concurrent gross metropolitan product growth rate is denoted as "Gross metro product". Joint tests report the significance levels of combined selected lagged terms. Results are estimated from Fama-MacBeth regressions with Newey-West adjustments. ***, ** and * indicate significance at the 1% level, 5% level and 10% level, respectively.

EXHIBIT 8

Factors Affecting the Serial Correlations in Property Appreciation Rates

Panel A: The effect of GMP size "GMPsize"

Variable	[I] Return			Variable	[II] Return		
	Full Sample	Before 2007	After 2007		Full Sample	Before 2007	After 2007
Intercept	-0.001	0.000	-0.006	Intercept	-0.004	-0.003	-0.008
Return(-1)	0.641***	0.625***	0.717***	Return(-1s)	0.693***	0.679***	0.760***
Return(-2)	0.012	0.004	0.052	Return(-2s)	-0.058	-0.040	-0.140
Return(-3)	-0.173**	-0.152	-0.274**	Return(-3s)	-0.195**	-0.189**	-0.223
GMPsize	0.000	0.000	0.000	GMPsize	0.001	0.001	0.001
GMPsize * Return(-1)	0.052*	0.062*	0.004	GMPsize * Return(-1s)	0.025	0.038	-0.037
GMPsize * Return(-2)	-0.028	-0.018	-0.075	GMPsize * Return(-2s)	-0.007	-0.002	-0.030
GMPsize * Return(-3)	0.017	0.012	0.042	GMPsize * Return(-3s)	0.012	0.011	0.020
Gross metro product	0.263***	0.276***	0.200***	Gross metro product	0.303***	0.316***	0.243***
Number of observations	11252	9312	1940	Number of observations	11252	9312	1940
[Joint test]				[Joint test]			
Return(-2)+(-3)	-0.161	-0.148	-0.222	Return(-2s)+(-3s)	-0.252**	-0.229**	-0.363
GMPsize*(Return(-2)+(-3))	-0.010	-0.006	-0.033	GMPsize*(Return(-2s)+(-3s))	0.006	0.009	-0.011

Panel B: The effect of population density "popuden"

Variable	[I] Return			Variable	[II] Return		
	Full Sample	Before 2007	After 2007		Full Sample	Before 2007	After 2007
Intercept	-0.002	-0.001	-0.006	Intercept	-0.002	-0.002	-0.004
Return(-1)	0.716***	0.713***	0.732***	Return(-1s)	0.702***	0.723***	0.603***
Return(-2)	-0.056	-0.025	-0.203*	Return(-2s)	-0.054	-0.026	-0.189*
Return(-3)	-0.095***	-0.087**	-0.133**	Return(-3s)	-0.142***	-0.129***	-0.206***
Popuden	0.000	0.001	-0.003	Popuden	0.002	0.004	-0.004*
Popuden * Return(-1)	0.093*	0.121*	-0.040	Popuden * Return(-1s)	0.054	0.075	-0.042
Popuden * Return(-2)	0.004	0.022	-0.082	Popuden * Return(-2s)	0.017	0.043	-0.108
Popuden * Return(-3)	-0.024	-0.039	0.049	Popuden * Return(-3s)	-0.026	-0.053	0.102
Gross metro product	0.270***	0.282***	0.214***	Gross metro product	0.309***	0.320***	0.257***
Number of observations	11252	9312	1940	Number of observations	11252	9312	1940
[Joint test]				[Joint test]			
Return(-2)+(-3)	-0.150***	-0.111**	-0.336**	Return(-2s)+(-3s)	-0.196***	-0.154***	-0.395***
Popuden*(Return(-2)+(-3))	-0.020	-0.017	-0.032	Popuden*(Return(-2)+(-3))	-0.009	-0.009	-0.006

Panel C: The effect of regulatory index "regindx"

Variable	[I] Return			Variable	[II] Return		
	Full Sample	Before 2007	After 2007		Full Sample	Before 2007	After 2007
Intercept	0.000	0.002	-0.006	Intercept	0.001	0.002	-0.005
Return(-1)	0.730***	0.730***	0.734***	Return(-1s)	0.693***	0.709***	0.617***
Return(-2)	-0.028	0.013	-0.225**	Return(-2s)	-0.018	0.027	-0.233**
Return(-3)	-0.094***	-0.093***	-0.104**	Return(-3s)	-0.136***	-0.134***	-0.146***
Regindx	0.001	0.002	-0.002	Regindx	0.002	0.003	-0.003
Regindx * Return(-1)	0.109***	0.121***	0.049	Regindx * Return(-1s)	0.093***	0.110***	0.016
Regindx * Return(-2)	-0.116***	-0.111***	-0.142***	Regindx * Return(-2s)	-0.121***	-0.123***	-0.114**
Regindx * Return(-3)	0.011	-0.003	0.077**	Regindx * Return(-3s)	0.021	0.010	0.073**
Gross metro product	0.251***	0.260***	0.210***	Gross metro product	0.294***	0.302***	0.260***
Number of observations	11252	9312	1940	Number of observations	11252	9312	1940
[Joint test]				[Joint test]			
Return(-2)+(-3)	-0.122**	-0.079	-0.329**	Return(-2s)+(-3s)	-0.154***	-0.108**	-0.379**
Regindx * (Return(-2)+(-3))	-0.106***	-0.114***	-0.065	Regindx * (Return(-2s)+(-3s))	-0.100***	-0.113***	-0.041

This table reports the effect of three factors (gross metropolitan product size, population density, and regulation index) on the serial correlation in property appreciation rates using Equation (8). The property appreciation rate is measured by the FHFA HPI growth rate and is denoted as "Return". In a type [I] regression, the independent variables include the 1-year, 2-year and 3-year lagged property appreciation rates. In a type [II] regression, the independent variables include 1-year, 2-year and 3-year lagged property appreciation rates that are further lagged by 1 quarter (therefore, the independent variables are essentially the 5-quarter, 9-quarter and 13-quarter lagged property appreciation rates). "GMPsize" is the natural logarithm of the GMP level in each MSA during the quarter. "Popuden" is the population density dummy, which is 1 if the population density (matched to the 2000 land area) of the MSA is at or higher than the median of the 97 MSAs in the sample in each year. "Regindx" is Wharton Residential Land Use Regulatory Index, estimated by Gyourko, Saiz and Summers (2008). Gross metro product is a control variable for property appreciation rate, which is measured as the concurrent growth rate of gross metropolitan product in each MSA. Joint tests report the significance levels of combined selected lagged terms. Results are estimated from Fama-MacBeth regressions with Newey-West adjustments. ***, ** and * indicate significance at the 1% level, 5% level and 10% level, respectively.

[1] See for example, Corradin and Popov (2012) and Adelino, Schoar and Severino (2013).

[2] Gorton (2009a, 2009b) argues that the fall in housing prices led to the collapse of trust in the credit markets, which eventually led to the subprime panic in 2008.

[3] See also, Case and Shiller (1989) and Campbell, Davis, Gallin and Martin (2009).

[4] See Stein (1995), Lamont and Stein (1999), and Ortalo-Magné and Rady (2006) for a discussion and evidence that financial constraints, e.g., down payment requirements, influence owner-occupied housing prices.

[5] The myopia assumption rules out the possibility that someone planning a future move to a booming city buys a house in advance in anticipation of a price rise. Directly modeling the costs associated with separating housing investment and consumption choices would considerably complicate our model but would result in similar implications. However, on the other hand, Beracha and Wintoki (2013) provide evidence that abnormal search intensity for real estate in a city can help predict the city's future abnormal housing price change. their findings hold even after they control for momentum in house prices

[6] In related work, Wheaton (1999) develops a model that also incorporates myopic investors and supply lags, to study the price dynamics in commercial property markets.

[7] Since they also consider positively correlated demand shocks, it is possible to get positive short-term serial correlation of appreciation rates in their model. However, they argue that a weakness of their calibrated model is its inability to match the positive serial correlation observed in the data.

[8] It should be noted that Nelson and Plosser (1982) report that the autocorrelations of the annual growth rates of macroeconomic variables (such as GNP, employment and wages) are significantly positive at 1-year lag and insignificant over longer horizons. Cochrane (1988) also reports that GNP growth is positively autocorrelated at short lags and has weak and possibly insignificant negative autocorrelation in the long run.

[9] There is a growing literature that studies the price elasticity of housing supply (see, for example, Mayer and Somerville (2000), Green, Malpezzi and Mayo (2005), and Wang, Chan and Xu (2012)). These studies report that the change in the housing supply rates (or levels) is significantly affected by past changes in price.

[10] For a discussion of the repeat sales approach, see Bailey et al. (1963) and Case and Shiller (1987).

[11] Calhoun (1996) provides a detailed comparison of the trade-offs between using the FHFA price indexes and other indexes, such as the S&P/Case-Shiller indexes.

[12] We obtain the index from the Wharton Real Estate Research Center (http://real.wharton.upenn.edu/~gyourko/LandUseSurvey.htm).

[13] The alternative economic indicators that we examine include the business bankruptcy growth rate (obtained from Moody's Economy.com), the personal bankruptcy growth rate (obtained from Moody's Economy.com) and the per capita income growth rate (obtained from the Bureau of Economic Analysis).

[14] Note that for the 1980s, the starting quarter with data is 1983 Q1.

[15] See Quigley (1998) for a discussion of these spillovers and how they might relate to economic growth.

[16] To facilitate the interpretation of the interaction term we represent density with a dummy that is 1 if the population density (matched to the 2000 land area) of the MSA at a particular quarter is at or higher than the median of the 97 MSAs in this quarter.