National and Regional Housing Vacancy: Insights Using Markov-switching Models

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Abstract

We examine homeowner vacancy rates over time and space using Markov-switching models. Our theoretical analysis extends the Wheaton (1990) search and matching model for housing by incorporating regime-switching behavior and interregional spillovers. Such an approach is strongly supported by our empirical results. Our estimations allow us to examine differences in vacancy rates as well as explore the possibility of asymmetries within and across housing markets, depending on the state/regime of a given housing market. Estimated vacancy rates, conditional on the vacancy regime, vary across regions in all models. Models allowing for interregional effects tend to perform better than models lacking this feature. These models track vacancies well. Noteworthy is their performance during the Great Recession/Financial Crisis. The importance and diversity of interregional effects are demonstrated, and vacancies in a specific Census region are affected by vacancies in other regions. Moreover, the sizes of these effects depend on the vacancy state of the specific region.

JEL Codes: R31, C24, R11

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Introduction

Vacancies in the housing market (i.e., unoccupied housing units) are similar to unemployment in the labor market in that some level is desirable and expected in a well-functioning market. For example, homeowners may experience changes in their family or employment situations such that their existing house no longer meets their needs, and, after a search, more appropriate housing is purchased. Thus, until the first house is sold, a given homeowner may own two houses, one of which is vacant. Vacancies also arise for other reasons. For example, newly-constructed houses may be vacant for a period before occupancy.[1]

In our analysis, we explore the possibility that vacancy rates depend on the state of the housing market. Specifically, we estimate separate vacancy rates for a low-vacancy state and for a high-vacancy state. Upon entering a specific regime, the regime is highly persistent. Numerous circumstances can cause vacancies to rise and lead to a high-vacancy state. National and local recessions as well as geographic shifts in demand can generate rising vacancies and lead to what we characterize as a high-vacancy state.

Persistently high vacancy rates can indicate housing market problems. For example, high and geographically-concentrated vacancy rates can indicate an inefficient allocation of resources and can breed vandalism and crime. In addition, local governments may confront substantial management and demolition costs in dealing with abandoned, run-down houses, while financial intermediaries may incur costs/losses in taking possession of and ultimately selling vacant houses associated with foreclosures.

Recent history provides a stark example of a recession that propelled a sharp upward movement in vacancy rates. As shown in Figure 1, during the housing crisis associated with the Great Recession, homeowner vacancy rates in the United States reached levels far greater than at any time since measurement began in the mid-1950s. Rates reached 2.9% during the housing crisis. As far back as records have been kept, rates had always been below 2.0%.

Homeowner vacancy rates likely differ across space and can change over time.[2] Various factors, such as the cost of holding vacant units, search costs and the matching process, expectations about future housing prices, demand for specific housing characteristics, the quantity and quality of intermediaries, the specific characteristics of the existing housing stock,

[1] Two other reasons might also be noted. An individual might own two houses, one of which is occupied most of the year and the other which is used for vacations. The vacation house will likely be unoccupied for large portions of a year. Such vacancy can be viewed as intentional and does not suggest any housing market problem. What is termed long-term vacancy (i.e., nonseasonal housing units that have been vacant for an unusually long period of time) suggest the possibility of some fundamental problem, such as a declining neighborhood. See Molloy (2016) for a recent analysis of long-term vacancies.

[2] While our research examines owner-occupied housing, a similar analysis could be done for rental property. An early study is Gabriel and Nothaft (1988). From the mid-1950s to the present, the correlation between homeowner and rental vacancy rates is 0.77. These rates move in opposite directions prior to the Great Recession, a period worthy of a separate study.

transaction costs, land use regulations, and credit market imperfections can differ locally and over time.[3] These differences across space and changes over time create the possibility of various vacancy rates. We attempt to explain the spatial variation theoretically by extending the Wheaton (1990) search and matching model for housing to include game-theoretic aspects, and to include a direct connection between interregional housing market differences and interregional labor market relationships. We allow the interregional labor market relationships to vary across economic states of the world.

Empirically, we provide insights into vacancy rates for the United States and the four Census regions via Markov-switching models. In the context of housing vacancy, this is the first known research that uses Markov-switching models.[4] These models allow us to deal with the large changes in vacancy rates during major economic shocks and recoveries. They also allow us to test the level of interdependence of the Census regions, as well as how that interdependence varies across regimes, by incorporating other regions' vacancy rates into the empirical models. Our research appears to be the first attempt to empirically identify and explain interregional vacancy relationships. Of particular interest is how our models perform around the financial crisis and Great Recession, a period of substantial upheaval and distress in U.S. housing markets.[5]

The rest of the paper proceeds as follows. We will review the literature focused on vacancies and we will lay out our extension of the Wheaton (1990) model. We will then discuss the basics of Markov-switching models, followed by an examination of our empirical results. The last section will conclude.

Housing Vacancy: Background Literature

Vacant housing is illustrated in Figure 2 via a simple supply and demand framework. Let the supply of housing units be fixed at S_o. With a demand for occupied housing units, D_o^o, and a total demand for housing units, D_o^+, then the equilibrium price would be P_o, the equilibrium quantity of occupied housing units would be D_o, and the equilibrium quantity of all housing units would be the same as the quantity supplied of all housing units (i.e., S_o). Associated with this equilibrium is a vacancy rate (VR) equal to $((S_o - D_o)/S_o) \times 100$.

[3] See Fritzsche and Vandrei (2014) for a discussion of the theoretical causes of vacancies and a summary of empirical findings. A related paper is by Cheshire, Hilber, and Koster (2015) finds that regulations restricting new house construction increases rather than decreases vacancy rates. Regulations leads to higher prices providing incentives for occupying houses, but also impede the matching process. Empirically, for a sample of local housing markets in England, this latter effect, which tends to increase vacancies, dominates the former effect.

[4] For a related article not using Markov switching, see Zabel (2016). Zabel develops and estimates a dynamic model of the housing market in which vacancies are related to an error-correction process.

[5] For a summary of housing price developments during the financial crisis, see Cohen, Coughlin, and Lopez (2012). For a review of recent literature focused on foreclosures and sales of distressed properties, see Cohen, Coughlin, and Yao (2016).

Next, assume demand for housing declines to D_1^+ for all units and D_1^o for occupied units. Such a decline puts downward pressure on housing prices. If price adjusts completely and instantaneously, then the new equilibrium price would be P_1 and the equilibrium quantities of occupied and total housing would be unchanged. Vacancies and the associated vacancy rate would also remain unchanged.

However, there are frictions that might prevent a complete and instantaneous adjustment. Molloy (2016) provides a number of arguments and references that would lead one to expect that price would not fall immediately to P_1. Goodman and Ittner (1992) argue that owners tend to overestimate the value of their property and Genesove and Mayer (2001) find a reluctance to sell property for less than property owners judge as its worth.[6] Especially when demand declines, property owners might not recognize the decline in the value of their property. Anenberg (2016) and Guren (2014) argue that owners set their asking prices based on the transactions prices of comparable properties sold recently. Thus, given a decrease in demand, some owners might have unrealistic expectations concerning the values of their property. Finally, if an owner is offered less than the mortgage amount, a common occurrence during the recent housing crisis, then sales become quite complicated. To complete the sale, either the lender must forgive the difference between the mortgage amount and the transaction price or the seller must make up the difference.

In light of the preceding frictions, assume price declines only to P_2. Given this partial adjustment, the quantity of occupied units is D_1. As a result, the vacancy rate, VR, increases to $((S_o - D_1)/S_o) \times 100$, higher than its previous rate.[7] Turning to the case of an increase in demand, one can also argue that price will not adjust completely and instantaneously. If so, then the vacancy rate will decline below its previous rate.

The next question is what happens when more time is allowed for adjustments in the housing market. Because a supply curve for housing for periods longer than the short run likely has a positive slope and can shift, the quantity of housing units can adjust upward via new construction and downward by depreciation/teardowns. On the demand side, whether the shock is temporary or permanent is of utmost importance. If the shock is temporary, then one should expect price and vacancy to return to their original values. On the other hand, if the shock is permanent, then price and quantity will adjust further and their effects on the vacancy rate are

[6] The loss aversion argument of Genesove and Mayer (2001) illustrates how psychological concepts from behavioral economics can affect vacancy rates, a topic discussed in Fritzsche and Vandrei (2014). Stein (1995) offers another argument related to Genesove and Mayer (2001). In a declining house price environment, potential sellers are adversely affected by the resulting decline in wealth and liquidity. This produces a reluctance to sell because ever-lower prices decrease the potential seller's options for relocating as their capability of making a given downpayment is reduced.

[7] The effect of vacancies on housing prices has been a topic of increased attention due to the housing bubble. See Zabel (2016) and Whitaker and Fitzpatrick (2013).

uncertain without more detailed information on various quantitative relationships as well as the cause of the shock.[8]

The foundations for the preceding supply and demand discussion are a search and matching model. While somewhat dated today, Wheaton (1990) provided a basic search and matching model that yields a vacancy rate. Moreover, the model is more than sufficient for illustrating the basics of the search and matching process.[9]

Assume that there are two types of households (e.g., families and singles) and two types of housing units (e.g., large and small). Households are viewed as "matched" when a family is in a large unit and a single is in a small unit and "mismatched" when a family is in a small unit and a single is in a large unit. A matched household becomes mismatched when a single becomes a family or a family becomes a single.[10] A household moves from mismatched to matched by finding and purchasing the other appropriate unit. Then the previously occupied house is put up for sale. An additional simplification in Wheaton's model is that while households can change between types, the aggregate distribution of households by type is stable. These dynamics can be expressed as follows:

(1) $\dot{H}_1 = \beta_2 H_2 - \beta_1 H_1$

and

(2) $\dot{H}_2 = \beta_1 H_1 - \beta_2 H_2$,

where H_i is the total number of households of type i = 1 and 2, β_i is the transition rate between types (e.g., β_1 is the transition rate from type 1 to type 2), and a solid dot (i.e., $\dot{}$) indicates the time rate of change of the household type. In the steady state (i.e., $\dot{H}_1 = \dot{H}_2$):

(3) $H_1/H_2 = \beta_2/\beta_1$.

At any time, a given household is in one of three occupancy states: 1) HM_i indicates a matched household (i.e., the household occupies an appropriate housing unit); 2) HD_i indicates a matched household with a house to sell (i.e., the household owns two units - one being appropriate and not for sale and the other inappropriate for them and for sale); and 3) HS_i indicates a mismatched household looking for an appropriate unit. The stock of each type of

[8] Colwell (2002) identifies two components of the demand for vacancies: a transactions component, which is associated with the natural vacancy state, and a speculative component. This speculative component is tied to expectations of future prices relative to current prices. When future prices are in line with current prices (i.e., neither too high or too low), then the speculative demand for vacancies is zero.

[9] Not surprisingly, the literature on this topic has advanced substantially since 1990. For a recent literature review see Han and Strange (2015). See Williams (1995) for a continuous time version of Wheaton's model. The role and impact of bargaining in the housing search process is examined by Ihlanfeldt and Mayock (2012) and by Merlo and Ortalo-Magné (2004). Piazzesi, Schneider and Stroebel (2015) extend the housing market matching literature by allowing for multiple market segments and heterogeneous searchers.

[10] Obviously, this is a major simplification. Households tend to move when a job change creates a large increase in commuting distance or the household experiences some other change in income or family size that makes a current house inadequate. Ihrke (2014) found that with-in county moves are associated with housing-related issues, while between-county moves are associated with job-related issues.

housing is fixed in the short run and is greater than the number of households of each type. Thus,

(4) $V_i = S_i - H_i > 0$ for $i = 1, 2$,

where V indicates vacant houses and S indicates the stock of houses.

A mismatched household cannot find an appropriate house instantaneously, so this leads to a search process that produces matches. The matching process for those mismatched households is $m_i HS_i$, which is the aggregate flow of house purchases. The matching is assumed to occur with a Poisson process, with m_i the rate at which matched houses of that type are found. The sales of vacant houses must also occur with a Poisson process, q_i. These sales must equal to the flow of house purchases. Thus,

(5) $q_i V_i = m_i HS_i$

With a fixed number of households and units of each type, households change states in the model according to the following differential equations:

(6) $\dot{HS}_i = -m_i HS_i - \beta_i HS_i + \beta_j HM_j$

(7) $\dot{HD}_i = -q_i HD_i + m_i HS_i + \beta_j HD_j - \beta_i HD_i$

(8) $\dot{HM}_i = -\dot{HS}_i - \dot{HD}_i$, $i = 1,2$, $j \neq 1$.

Equation (6) is the time rate of change of becoming mismatched. The first term is those who have become newly matched thus reducing the rate of becoming mismatched, the second term is those exiting from i (mismatched and looking) to j, and the third term captures the newly mismatched who are moving from j to i. Equation (7) is the time rate of change of those households being matched with a house to sell. The first term captures the sale of vacant houses of type i, thus reducing the rate of being matched with a house to sell. The second term captures those households who have become matched and now have a house to sell. The third term captures households who are newly matched with a type i house to sell. The fourth term captures those households who have changed from i into j. Equation (8) is time rate of change of those becoming matched, which is simply the difference between the negative of those households becoming mismatched and looking and those who have become matched with a house to sell.

Wheaton (1990) further simplifies the analysis by assuming that the two types of households are identical in number and behavior. With $\beta_1 = \beta_2$, $V_1 = V_2$, $H_1 = H_2$, $m_1 = m_2$, then $HS_1 = HS_2$, $HM_1 = HM_2$, and $HD_1 = HD_2$. The effect of this simplification is to reduce the system of six differential equations to the following two equations:

(9) $\dot{HS}_i = -HS(2\beta + m) + \beta H - \beta HD$

(10) $\dot{HD}_i = mHS(1 - HD/V)$

Equations (9) and (10) allow the determination of HS and HD. The resulting steady state is characterized by:

(11) $HS = (\beta(H - V))/(2\beta + m)$

and

(12) $HD = V.$

Equation (11) captures mismatched households looking to buy a house, while equation (12) captures matched households who have a (vacant) house to sell.

An Extended Search and Matching Model

Next, we extend Wheaton's (1990) model to more explicitly consider interregional effects and their relationship to the underlying labor markets.[11] One change is to incorporate a game-theoretic aspect in which those attempting to buy and sell vacant homes of a given type take the actions of all others as given. A second change is to modify the previous definitions to focus on two regions rather than on households in one region. Rather than mismatches due to owning a house that is inappropriately sized for a given household (i.e., a single owns a large house or a family owns a small house), mismatches are associated with a desire to live in one region, but owning a home in the other region. Hence, HS_i, HD_i, and HM_i are respectively those who live in region j and want to move to region i; those who happily live in region i, but still have a vacant home in region j; and those who happily live in region i. We also bring the labor markets into our model. Finally, we allow for two possible states of the world, one of which is a healthy labor market situation and the other is an unhealthy employment state. These two states will help motivate our subsequent empirical analysis, where we allow for two possible steady states.

First, considering the activities of buyers and sellers of vacant homes in region i, we use equations (6) and (7) from Wheaton (1990), slightly adjusted by acknowledging that $m_i\ HS_i = q_i\ V_i = q_i\ HD_j$:

(13) $\dot{HS_i} = -q_i\ HD_j - \beta_i\ HS_i + \beta_j\ HM_j$

(14) $\dot{HD_j} = -m_i\ HS_i + m_j\ HS_j + \beta_i\ HD_i - \beta_j\ HD_j.$

[11] For an alternative housing market model using a search-and-matching approach, see Lisi (2015). This model, similar to our model, highlights the existence of vacancies; however, in contrast to our model, does not address interregional effects.

We also extend the Wheaton model by incorporating an equation relating employment in region i, e_i, to migrations between i and j, as well as exogenous labor market characteristics (X_i) and their impacts (L_i):

(15) $\dot{e_i} = \frac{e_i}{H_i - HD_j}\left(q_i\, HD_j - q_j\, HD_i\right) + L_i X_i$, where H_i is the fixed (i.e., exogenous) number of houses in i.[12]

We describe parameters m, q, and β as functions of the labor market characteristics, i.e., X_i, X_j, and $cov(X_i, X_j)_{s_i}$. The subscript of the covariance term, s_i, indicates the state of the world region i is in, with the state being either one of relative labor market health or underperformance. For ease of presentation, we suppress the subscripts, s_i, in the analysis that follows, however it is important to keep in mind that underlying the m, q, and β parameters are varying labor market characteristics that imply multiple possible steady states. In general, macroeconomic health of the entire country, or of regions, is expected to be highly correlated with employment market health. Thus, the labor market characteristics can proxy for many other types of factors that can impact the growth rate of employment (and later on, of vacancies).

Hence, employment is influenced by migrations between the two regions and exogenous labor market characteristics. Meanwhile, the housing market dynamics are influenced by labor market conditions in each region and the economic relationship between the two regions, the latter varying in the economic state of i.

We consider a particular steady state for region i for this model in which the HS_i and HD_j households take the actions of all other household types as given and there are no changes in region i employment, vacancies, and unmatched households. Setting (13) equal to zero and solving for HS_i, we obtain:

(16) $$HS_i = \frac{\beta_j\, HM_j - q_i HD_j}{\beta_i}.$$

Substituting (16) into (14) and solving for HD_j, we obtain the steady state value:

(17) $$V_i = HD_j = \frac{m_j\, HS_j + \beta_i\, HD_i - \frac{m_i \beta_j\, HM_j}{\beta_i}}{\beta_j - \frac{m_i q_i}{\beta_i}} = \frac{m_j\, HS_j + \beta_i\, V_j - \frac{m_i \beta_j\, HM_j}{\beta_i}}{\beta_j - \frac{m_i q_i}{\beta_i}}.$$

Substituting (17) into (15) and solving for e_i, we obtain the steady state value:

[12] Head and Lloyd-Ellis (2012); Head, Lloyd-Ellis, and Sun (2014); Rupert and Wasmer (2012); and Ioannides and Zabel (2017) are recent papers connecting housing and labor markets.

$$(18) \qquad e_i = \frac{-L_i X_i \left(H_i - \frac{m_j HS_j + \beta_i V_j - \frac{m_i \beta_j HM_j}{\beta_i}}{\beta_j - \frac{m_i q_i}{\beta_i}}\right)}{q_i \frac{m_j HS_j + \beta_i V_j - \frac{m_i \beta_j HM_j}{\beta_i}}{\beta_j - \frac{m_i q_i}{\beta_i}} - q_j V_j}.$$

Last, substituting (17) into (16), we obtain the steady state value:

$$(19) \qquad HS_i = \frac{\beta_j HM_j - q_i \frac{m_j HS_j + \beta_i V_j - \frac{m_i \beta_j HM_j}{\beta_i}}{\beta_j - \frac{m_i q_i}{\beta_i}}}{\beta_i}.$$

Thus, through the underlying dynamics, the housing market in a given region moves toward an equilibrium in accordance with the health of its and the other region's labor markets (implied by X_i, X_j, and $cov(X_i, X_j)_{s_i}$), as well as the substitutability/complementarity of labor in the two regions, the latter being implied by the covariance of labor market conditions. The low-vacancy rate can then be interpreted as the rate prevailing when each labor market is relatively healthy.

Focusing on the vacancy rate steady state equation, (17), we can rewrite the equation as:

$$(20) \qquad V_i = \alpha\, HS_j + \delta\, V_j - \gamma HM_j,$$

where $\alpha = \frac{\beta_i m_j}{\beta_i \beta_j - m_i q_i}$, $\delta = \frac{\beta_i^2}{\beta_i \beta_j - m_i q_i}$, and $\gamma = \frac{m_i \beta_j}{\beta_i \beta_j - m_i q_i}$. Given that the sign of each numerator is positive and the sign of the denominators could be positive or negative, the signs of α, δ, and γ are indeterminate. Thus, the relationships between V_i and HS_j, V_j, and HM_j can be positive or negative, depending on whether or not $\beta_i \beta_j > m_i q_i$. Also, we note that for now we suppress the s_i subscripts but emphasize that underlying α, δ , and γ are variables describing the health of the labor markets. This can lead to multiple possible steady state values for these parameters and in turn, multiple possible steady states for V_i. We add these state subscripts again in equation (21).

Let's examine this relationship in (20) in greater detail. Recall that β_i and β_j are the transition rates between regions and $m_i \ and \ q_i$ are the probability of a sale of a vacant house and the percent of mismatched households who buy a house, respectively. Therefore, if $\beta_i \beta_j > m_i q_i$, this implies that more vacant units in region 1 lead to more vacant units in region 2. In other words, this describes a situation when a relatively large share of households want to move to different regions, but a relatively low share of these mismatched households are purchasing homes, in which case vacancies move in tandem across regions. One would expect this situation to be the norm, as there are frictions that should lead to moving regions not occurring in the same period as the decision to move.

Finally, it is worth noting that when using contemporaneous values of V_j on the right hand side of (20), a regularity condition must hold for (20). Specifically, the absolute value of $\delta = \frac{\beta_i^2}{\beta_i\beta_j - m_i q_i}$ must lie between 0 and 1. This is due to feedback effects between regions i and j, which would imply explosive feedback effects if this regularity condition did not hold. Empirically, in our estimations below we use a lagged independent variable specification for V_j, as in (21), so in such a case the above regularity condition need not hold. We next describe our vacancy rates Markov-switching model estimations in more detail below.

A Markov-switching Model for Vacancy Rates

Given that the parameters of our theoretical model all depend on the state-dependent covariance of each region's labor markets, $cov(X_i, X_j)_{s_i}$, we can estimate equation (20) via a simple Markov-switching model. This is a model simplification, in the sense that the health of labor markets imply the health of the regional macroeconomy. Given that HS_j and HM_j, defined as those who live unhappily in region i and happily in region j, are difficult to measure in practice, we are restricted to estimating δ via the following Markov-switching equation:

$$(21) \qquad V_{i_t} = C_{s_t} + \delta_{s_t} V_{j_{t-k}} + \varepsilon_t,$$

where t indicates time; C_{s_t} is a state-dependent constant, consisting of $\widetilde{C}$ + $C_1 s_t$; δ_{s_t} is state-dependent, consisting of $\widetilde{\delta}$ + $\delta_1 s_t$; and ε_t is the error term.[13] Specifically, C and δ are comprised of two parts, state-invariant components, $\widetilde{C}$ and $\widetilde{\delta}$, and state-dependent components, $C_1 s_t$ and $\delta_1 s_t, where\ s_t = \{0, 1\}$. For ease of discussion, we henceforth refer to $s_t = 0$ as state 1, and $s_t = 1$ as state 2. In one sense, equation (21) is a simplified version of (20), where we are now only including vacancies in two regions. The k-period lags in (21) avoid the potential feedback effects that would be present if we had used contemporaneous values of the explanatory variables. Given that we are missing data on HS_j and HM_j when we estimate (21), and the fact that our model implies that the dynamics of those variables are governed by labor markets, labor market variables may also serve as good proxies for the right side of (20). However, a model with labor market

[13] The constant term, C_{s_t}, will capture the state-dependent average of $\alpha\, HS_j - \gamma HM_j$, but the variation of $\alpha\, HS_j - \gamma HM_j$ ends up in the error term. Migration rates, both inter-region and intra-region, are likely affecting vacancy rates. Although we are unable to infer anything directly about migration rates on vacancies, this is not a major concern in the present study as our primary focus is whether and how incorporating inter-regional vacancy dependencies affects the fit of our Markov-switching model.

variables on the right side of (20) is not the main focus of our analysis, and therefore we hone our attention on (21).

Data and Estimation Results

We estimate (21) using vacancy rate data for each of the four U.S. Census regions: Northeast, Midwest, South, and West. Before doing so, we estimate "simple," constant-only Markov-switching models:

$$V_{i_t} = C_{s_t} + \varepsilon_t \tag{22}$$

for the entire United States and the Census regions to analyze the basic regime switching properties of each vacancy rate.[14]

Regarding our data, the vacancy rate measures we use are the homeowner vacancy rates provided by the U.S. Census Bureau. The homeowner vacancy rate is defined as the ratio of vacant year-round housing units for sale to owner-occupied housing units plus vacant year-round housing units sold but awaiting occupancy plus vacant year-round housing units for sale, multiplied by 100. We then seasonally adjust these measures using the Census' X-13 package. The employment growth measures are quarterly log differences in seasonally adjusted employment, obtained from the Bureau of Labor Statistics, multiplied by 100.

Simple National and Census Region Models

Before examining the estimation results, let's re-examine the raw data for the vacancy rate for the United States from 1956:Q1 through 2017:Q4 . Figure 1 shows that the U.S. vacancy rate has normally been less than 2.0 percent. Only the period associated with the housing crisis exhibited rates in excess of 2.0 percent. Prior to the Great Recession, no period, even recessions, exhibited a national vacancy rate greater than 2.0 percent.

The results of a simple Markov switching model for the United States are shown in Table 1. State 1 (2) is the low- (high-) vacancy state, p_{11} (multiplied by 100 to yield a percentage) is the probability of remaining in state 1, and p_{21} (similarly adjusted) is the probability of moving from state 2 to state 1.

For the United States the estimated low-vacancy rate is 1.16 percent, while the high-vacancy rate is 1.81 percent. As can be seen by the estimates of p_{11} and p_{21}, both states are highly persistent. The probability of starting in state 1, the low-vacancy state, and remaining in state 1 is 98.3 percent. Thus, once the nation is in a specific state/regime the state is likely to persist. The probability of starting in state 2, the high-vacancy state, and moving to state 1 is 1.0

[14] The results of estimating (22) will implicitly provide state-conditional means and standard deviations in the form of constants and standard deviations of the error terms.

percent. These two probabilities also reveal the probability of starting in state 1 and moving to state 2, 1.7 percent, and the probability of starting in state 2 and remaining in state 2, 99.0 percent.

Figure 3 shows the actual vacancy rates compared with the estimated smoothed vacancy rate predictions and the estimated smoothed probabilities of the United States being in its high-vacancy state. With the exception of the Great Recession/Financial Crisis, the predicted vacancy rate tracks the actual vacancy rate quite closely. In turn, the estimated probability of the high vacancy states match the actual and estimated vacancy rates. Generally speaking, the estimated probabilities suggest that the low-vacancy state prevailed for the majority of the period from the mid-1950s to the early 1980s, while subsequently, the high vacancy state has dominated.

Taking a closer look at the underlying data, one might argue for a three regime model, with the regimes covering mid-1950s-early1980s, early 1980s to mid-2000s, and then the period covering the Great Recession/Financial Crisis and its aftermath. However, we found a simple three-regime model would not converge. What is evident from our estimation is that the United States housing market has not fully recovered from the Great Recession.

Turning to the estimates for the Census regions, one observes much diversity across regions. The vacancy rate associated with the low-vacancy state varies across regions, ranging from 0.89 percent in the Northeast to 1.46 percent in the West. The rates in the Northeast and Midwest are below the national rate of 1.16 percent, while the rates in the South and West are above the national rate. Estimates for the high-vacancy state also reveal much diversity, ranging from 1.59 percent in the Northeast to 2.18 percent in the South. The rate for the high-vacancy state in the Northeast is below the national average, while each of the other regions is above the national average. It is also noteworthy that the national average is 15 basis points below the high-vacancy rate for the Midwest, 37 basis points for the South, and 36 basis points for the West. In fact, the national rate for the high-vacancy state is closer to the West's rate for the low vacancy state than the high-vacancy state. Finally, relative to its low-vacancy state, the Midwest shows the largest difference of 83 basis points and the Northeast shows the smallest difference of 70 basis points.

Concerning persistence, the results reveal that a given vacancy state in one quarter is likely to prevail in the next quarter. The lowest probability of starting in a low vacancy state and staying in the low vacancy state in the next period is 97.7 percent in the South. The lowest probability of starting in a high vacancy state and remaining in the high vacancy state in the next period is 94.2 percent in the West.

For estimated results for the Northeast, Figure 4 reveals some similarities and some dissimilarities with the estimates for the United States as a whole. Similar to the U.S. estimates, the probability of being in a low-vacancy state is high from the mid-1950s to the early 1980s. A difference, however, is that these high probabilities continue for the Northeast until the late

1980s, while they stop for the nation. Similar to the national estimates, the estimates for the low-vacancy state are quite low for the late 1980s to the present. During this latter period, the actual vacancy rate shows much volatility relative to the predicted vacancy rate. This volatility becomes pronounced at the beginning of this century, years before the Great Recession. In terms of vacancy rates, the estimates provide no indication of an imminent return to a low-vacancy state.

For the Midwest, Figure 5 shows a pattern with similarities and dissimilarities to the United States. In contrast to the United States, the Midwest experienced a brief period of high vacancy in the early/mid 1980s and then returned to a low-vacancy state for more than a decade. The Midwest entry into its second period of high vacancy begins in roughly 2001/2002 and, similar to the United States, the region remains in the high-vacancy state. However, recent estimates suggest a slight movement toward the low-vacancy state. Also, similar to the U.S. results, with the exception of the Great Recession/Financial Crisis, the predicted vacancy rate tracks the actual vacancy rate quite closely.

For the South, Figure 6 shows more ups and downs than the United States and the Northeast and the Midwest. In contrast to the United States, estimates for the South indicate three periods of high vacancy – a brief period in the mid-1960s, a longer period in the mid-1980s to early 1990s, and finally a much lengthier period in late 1990s through the present. This last period begins long before the bursting of the housing bubble and even before the Midwest entered its most recent high vacancy state. Based on Figure 6, one sees that the South has generally been in its high-vacancy state since the mid-1980s. However, recent estimates suggest a slight movement toward the low-vacancy state. Also, similar to the U.S. results, with the exception of the Great Recession/Financial Crisis, the predicted vacancy rate tracks the actual vacancy rate quite closely.

For the West, Figure 7 shows a slightly larger upward movement in vacancy during the 1960s than the United States and other regions and a shorter duration of high vacancy during the recent housing crisis. With the exceptions of the late 1970s and the Great Recession/Financial Crisis, the predicted vacancy rate tracks the actual vacancy rate quite closely. What distinguishes the West from the nation and other regions recently, according to this simple model, is that the West has returned to its low vacancy state, while the United States and other regions have not. In fact, the West spent relatively little time in its high vacancy state in comparison to the United States and the other regions.

Switching Models for Census Regions Using Lagged Vacancy Rates

Next, we estimate (21) for the Census regions to explore the effect of all other Census regions' lagged vacancy rate on a region. That is, the South's vacancy rate will be a function of the Northeast's, Midwest's, and West's vacancy rates. Keep in mind that, because parameters are allowed to switch, state 1 (2) will not always be the low (high) state, although that is almost always the case. For ease of discussion and because it is true at almost every point in time for every region, we will refer to state 1 (2) as the low (high) state, but, for transparency, we have produced figures displaying actual vacancy rates, estimated vacancy rates, and estimated state probabilities.

We use lags of the other regions' vacancy rates for two main reasons: one is that the lags allow us to explicitly consider the exogenous impacts of one housing market on another, and the other is that it is reasonable to believe the information set of housing market participants in a given region have an information set made up of lags of other regions' housing market characteristics, and not contemporaneous information. See Table 2 for results using a two-quarter lag for the vacancy rate.[15] Regardless of the region, using information criteria,, both BIC and AIC, the results in Table 2 indicate substantial improvement over the results in Table 1. Also, regardless of the region, the results in Table 2 show that the probability of a region remaining in a specific vacancy state is high, always in excess of 95 percent.

Generally speaking, regardless of whether a region can be characterized as being in a high- or low-vacancy state, higher vacancy rates in other regions tend to be associated with higher vacancy rates for the region being examined. Of the 17 relationships that are statistically significant, 15 exhibit a positive relationship. Thus, for a specific region, higher levels of lagged vacancy rates in other regions are generally associated with a higher vacancy rate in the region. Our result is consistent with an argument suggesting that increased vacancy rates inhibit mobility via home-ownership lock-in. Lock-in might preclude the option of moving from one region to another.

Turning to specific regions, let's start by examining the results for the Northeast.[16] A higher vacancy rate in the Midwest has roughly the same positive marginal effect on the vacancy rate in the Northeast, regardless of the vacancy state in the Northeast. (A similar strong connection is seen in the Midwest results – that is, the lagged Northeast vacancy rates affect the

[15] Results using lags of either one quarter or three quarters produced similar results. The two-quarter results are highlighted because of an overall slightly better AIC value. Models using multiple lags of vacancy rates became too complex and failed to converge.

[16] These results are based on the entire sample, covering 1956:Q1-2017:Q4. To address a discussant's question about the sensitivity of our results to this sample, we ran additional Markov-switching models in which we eliminated the first eleven years of data, and also (separately) in which we eliminated the last eleven years of data (i.e., the period during and after the most recent housing crisis). We concluded that retaining the full sample is the preferred approach for the following reasons. First, we need a long time series of data for the Markov-switching models to converge and have statistical power. Considering smaller samples would likely be stretching the envelope in this respect. Second, the significance of the coefficients is not sensitive to dropping the first eleven years of data. Finally, when we drop the last eleven years of data, we have some relatively minor differences in the significance of the parameter estimates. However, in general, vacancy forecasts for the period 2007-2017 using the full sample (see, e.g., Figures 8 through 11) perform well. If we were to drop the last eleven years of data, while there may or may not be some improvement in the forecasts of the earlier years, we would not be able to examine (or forecast) vacancies during the housing crisis. For all these reasons, we have chosen to retain the full sample period of 1956:Q1-2017:Q4 in our analysis. Detailed tables and figures of the parameter estimates and forecasts, respectively, for the subsamples described in this footnote are available upon request.

Midwest.) A higher vacancy rate in the South tends to increase the vacancy rate in the Northeast when the Northeast is in its low vacancy state; a higher vacancy rate in the South tends to have no effect when the Northeast is in its high vacancy state. A higher vacancy rate in the West tends to have no effect when the Northeast is in its low vacancy state and tends to reduce the vacancy rate in the Northeast when the Northeast is in its high vacancy state. Note that the constant estimates make sense as one would expect higher levels for the high-vacancy state than for the low-vacancy state.

An examination of Figure 8 allows for some additional observations about the results. For the entire time series, the predicted vacancy rate tracks the actual vacancy rate quite closely. Thus, the interregional effects allow the predicted vacancy rate to track the actual vacancy rate even during the Great Recession/Financial Crisis. A comparison of Figure 8 with Figure 4 reveals that the estimation using lagged vacancy identifies a low-vacancy state in the first half of the 2000s that is not present in the estimation underlying Figure 4.

Turning to the results for the Midwest, a higher vacancy rate in the South tends to have a positive effect on the vacancy rate in the Midwest, with the effect being much larger when the Midwest is in its high vacancy state. (A similar strong connection is seen in the South estimation results – that is, the lagged Midwest vacancy rates affect the South.) A higher vacancy rate in the West tends to have no impact on vacancy in the Midwest. A higher vacancy rate in Northeast tends to have a positive effect on the vacancy rate in the Midwest, with the effect being similar regardless of the vacancy state in the Midwest. Recall that a similar strong connection is seen in the Northeast estimation results – that is, the lagged Midwest vacancy rates affect the Northeast.

An examination of Figure 9 allows for additional observations about the results. For the entire time series, the predicted vacancy rate tracks the actual vacancy rate quite closely. Thus, once again, the interregional effects allow the predicted vacancy rate to track the actual vacancy rate even during the Great Recession/Financial Crisis. A comparison of Figure 9 with Figure 5 reveals that the estimation using lagged vacancy identifies very brief periods of high vacancy in the late 1950s and early 1960s, as well as a return to the low state in the last few quarters, that are not present in the estimation underlying Figure 5.

For the South, a higher vacancy rate in the Midwest tends to have a positive effect on the vacancy rate in the South, with the effect being much larger when the South is in its high vacancy state. Recall that a similar strong result is seen in the Midwest results – that is, the lagged South vacancy rates affect the Midwest. A higher vacancy rate in the West tends to have no impact on vacancy in the South when the South is in its low vacancy state and a positive effect when the South is in its high vacancy state. A higher vacancy rate in the Northeast tends to have a positive effect on the vacancy rate in the South, with the effect being much larger when the South is in its low vacancy state. Meanwhile, recall that lagged vacancy rates in the South have only a small effect on Northeast.

An examination of Figure 10 allows for some additional observations about the results. A point made previously for other regions is that the predicted vacancy rate tracks the actual vacancy rate quite closely for the entire time series. Thus, the interregional effects allow the predicted vacancy rate to track the actual vacancy rate even during the Great Recession/Financial Crisis. A comparison of Figure 10 with Figure 6 reveals the estimation using lagged vacancy identifies extended periods of high vacancy throughout the 1960s and in in the mid/late 1970s and a return to low vacancy in recent years that are not present in the estimation underlying Figure 6.

For the West, a higher vacancy rate in the Midwest tends to have a positive effect on the vacancy rate in the West, with the effect being similar regardless of the vacancy state in the West. A higher vacancy rate in the South tends to have no impact on the vacancy rate in the West when the West is in its low vacancy state and a positive effect when the West is in its high vacancy state. A higher vacancy rate in the Northeast also has no effect on the vacancy rate in the West when the West is in its low vacancy state and a negative effect when the West is in its high vacancy state.

An examination of Figure 11 allows for some additional observations about the results. Consistent with the results for the other regions, the predicted vacancy rate tracks the actual vacancy rate quite closely for the entire time series. Lastly, a comparison of Figure 11 with Figure 7 shows some substantial differences. Figure 11 shows a high vacancy period in the mid-1970s that is not present in Figure 7. More significantly, Figure 11 reveals a high vacancy state throughout the 1980s and 1990s in contrast to a high vacancy state only for the mid- to late 1980s in Figure 7.

Overall, these results reveal that other regions' housing markets explain well the movements in a given region's vacancy rate. Further, the large differentials in coefficients across regimes support our model's implication that relationships vary across states of the world. The results also indicate the ambiguity of the sign of vacancy rate relationships present in our model, with two coefficients being negative and the others positive. We discussed the logic behind a positive coefficient above, but the two negative coefficients are also reasonable: They both occur for high-vacancy states, where implicit job market conditions should lead to the likelihood of wanting to move to the region of interest to be low. Meanwhile, it may be relatively easy to find housing in another region if the high-vacancy state is the result of a nationwide recession. Considering the large differences in how much a given region's vacancy rate influences others, it seems economic gravity plays a role, which aligns with our assumption of the role of labor market covariance. Two areas, the Northeast and the Midwest, which were respectively the U.S. financial and manufacturing centers for much of our time series, each have very large effects on the other regions' vacancy rates.

Test for the Necessity of Switching Parameters

We carry out the Carrasco, Hu, and Ploberger (2014) tests to examine the justification for the use of switching parameters for each model presented in Table 2. The p-values from the tests are provided in Table 3. For the supremum-type test, we are able to reject the null hypothesis of switching being unnecessary for the Northeast and Midwest models. For the exponential-type test, we are able to reject the null hypothesis for all four models. While we don't explicitly calculate the power of the tests for our models, Carrasco, Hu, and Ploberger (2014) find consistently higher power for the exponential-type test across multiple simulations. Thus, we find the use of switching parameters appropriate for all four models.

Conclusion

We extend the Wheaton (1990) model of search and matching for housing to allow for labor market steady state and interaction of housing types across regions. Our empirical analysis is motivated by the theory, and we examine homeowner vacancy rates using Markov-switching models. We estimate a national model and models for regional housing markets. These models identify two states, one being a low-vacancy state and the other being a high-vacancy state. While there are numerous similarities between the national and regional results and the across-regions results, it is clear that no two regions are identical. Our estimations allow us to identify and examine differences in vacancy rates as well as explore the possibility of asymmetries within and across housing markets depending on the state/regime of a given housing market.

The results from a basic empirical model indicate that, overall, from the perspective of vacancies, the U.S. housing market has not fully recovered as of year-end 2016 from the Great Recession/Financial Crisis. Based on Census regions, only the West has returned to its low-vacancy state. Regardless of the models estimated, the natural rate of vacancy varies across regions, with a range from 0.89 percent in the Northeast to 1.46 percent in the West. A similar conclusion pertains to estimates across regions of their high vacancy states.

After extending the Wheaton (1990) model to allow for interregional effects driven by labor market conditions and relationships, we examine the empirical relationships between a Census region's vacancy rate and other regions' vacancy rates, and compare those to relationships between a region's vacancy rate. The results indicate the importance and diversity of interregional effects. Generally speaking, the West tends to be relatively less affected by other regions and tends to affect other regions less than the relationship between and among other regions. Models allowing for interregional effects tend to perform better than the basic model. Noteworthy is the fact that these models track vacancies well, and substantially better during the Great Recession/Financial Crisis. Not surprisingly, the Great Recession/Financial Crisis and its aftermath affect the overall results in a number of identifiable cases.

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Table 1

Markov-switching Models: Constant-only Models

	United States	**Northeast**	**Midwest**	**South**	**West**
State 1					
Constant	1.1644***	0.8907***	1.1346***	1.4075***	1.4595***
	(0.0195)	(0.0150)	(0.0225)	(0.0271)	(0.0230)
Sigma	0.1546	0.1627	0.2044	0.2554	0.2616
State 2					
Constant	1.8055***	1.5918***	1.9611***	2.1809***	2.1652***
	(0.0307)	(0.0273)	(0.0582)	(0.0341)	(0.0624)
Sigma	0.3724	0.2962	0.4716	0.3652	0.3623
p11	0.9834	0.9958	0.9892	0.9773	0.9831
p21	0.0103	0.0043	0.0162	0.0204	0.0575
Observations	248	248	248	248	248
Log-Likelihood	-42.50	19.10	-49.69	-78.48	-60.24
BIC	118.1	-5.124	132.5	190.0	153.6
AIC	97.01	-26.20	111.4	169.0	132.5

Notes: *, **, *** denote 10%, 5%, and 1% statistical significance, respectively. Standard errors in parentheses.

Table 2

Markov-switching Models: 2-Quarter Lagged Vacancies of Other Regions

	Northeast	**Midwest**	**South**	**West**
State 1				
Northeast Vacancy Rate		0.3002***	0.6853***	-0.0182
		(0.0446)	(0.0516)	(0.0749)
Midwest Vacancy Rate	0.3896***		0.1956***	0.3621***
	(0.0515)		(0.0585)	(0.0785)
South Vacancy Rate	0.0906*	0.1729***		-0.0296
	(0.0506)	(0.0542)		(0.0888)
West Vacancy Rate	-0.0685	-0.0190	0.0110	
	(0.0434)	(0.0408)	(0.0617)	
Constant	0.4275***	0.5453***	0.4317***	0.9003***
	(0.0673)	(0.0626)	(0.0665)	(0.0783)
Sigma	0.1581	0.1297	0.1379	0.1724
State 2				
Northeast Vacancy Rate		0.3345***	0.3885***	-0.1997***
		(0.0885)	(0.0549)	(0.0645)
Midwest Vacancy Rate	0.3852***		0.4499***	0.4092***
	(0.0731)		(0.0423)	(0.0599)
South Vacancy Rate	0.0123	0.5220***		0.3068***
	(0.0999)	(0.0845)		(0.0727)
West Vacancy Rate	-0.1415**	0.0451	0.1488***	
	(0.0684)	(0.0834)	(0.0443)	
Constant	1.2497***	0.2886***	0.5998***	0.9084***
	(0.1154)	(0.1114)	(0.0674)	(0.0807)
Sigma	0.1650	0.2436	0.1705	0.2162
p11	0.9880	0.9735	0.9623	0.9544
p21	0.0172	0.0460	0.0342	0.0349
Observations	246	246	246	246
Log-Likelihood	86.07	64.11	80.57	22.96
BIC	-106.1	-62.15	-95.08	20.13
AIC	-148.1	-104.2	-137.1	-21.93

Notes: *, **, *** denote 10%, 5%, and 1% statistical significance, respectively. Standard errors in parentheses.

Table 3

P-Values for Carrasco, Hu, and Ploberger (2014) Test: 2-Quarter Lagged Vacancies of Other Regions

	Northeast	**Midwest**	**South**	**West**
SupTS	0.005	0.039	0.212	0.265
ExpTS	0.000	0.000	0.000	0.002

Figure 1

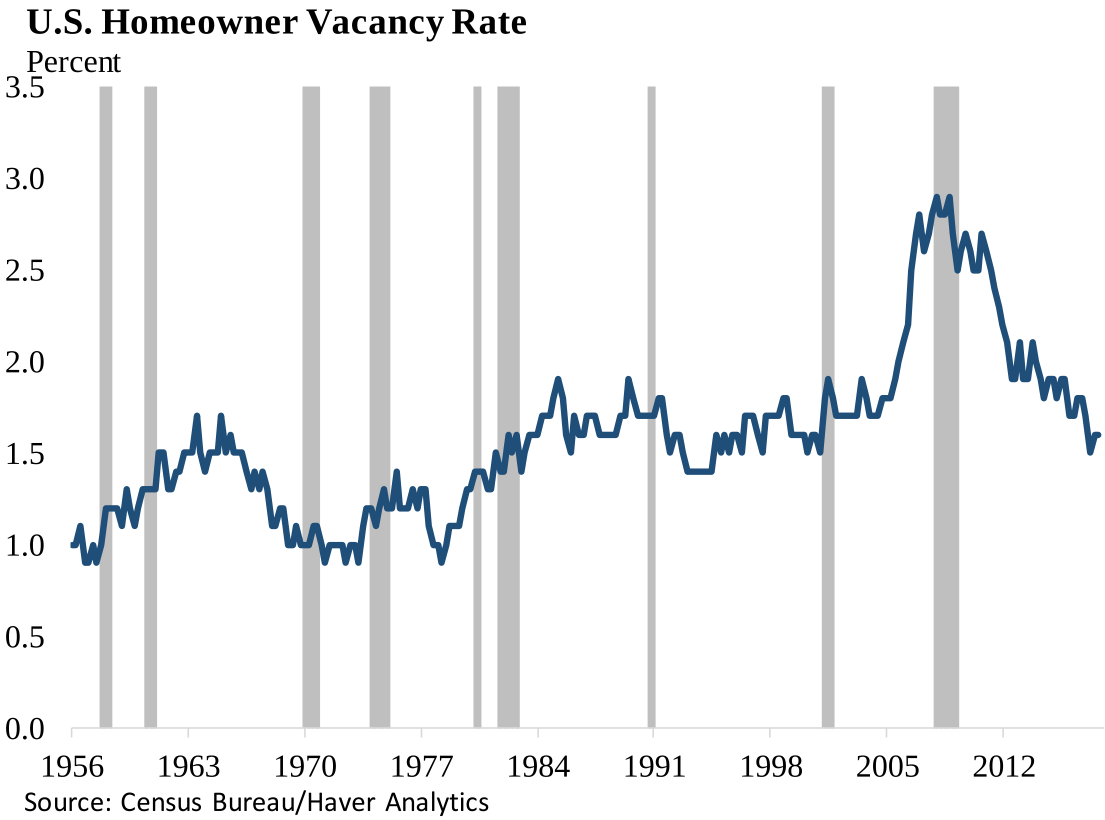

U.S. Homeowner Vacancy Rate
Percent
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1956
1963
1970
1977
1984
1991
1998
2005
2012
Source: Census Bureau/Haver Analytics

Figure 2

The Housing Market and Vacancy Rates

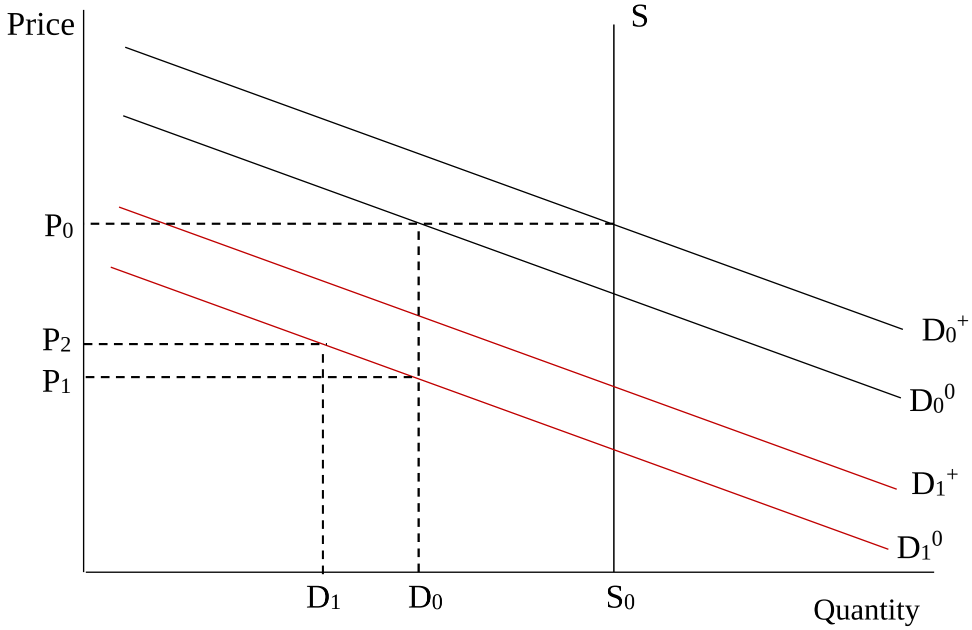
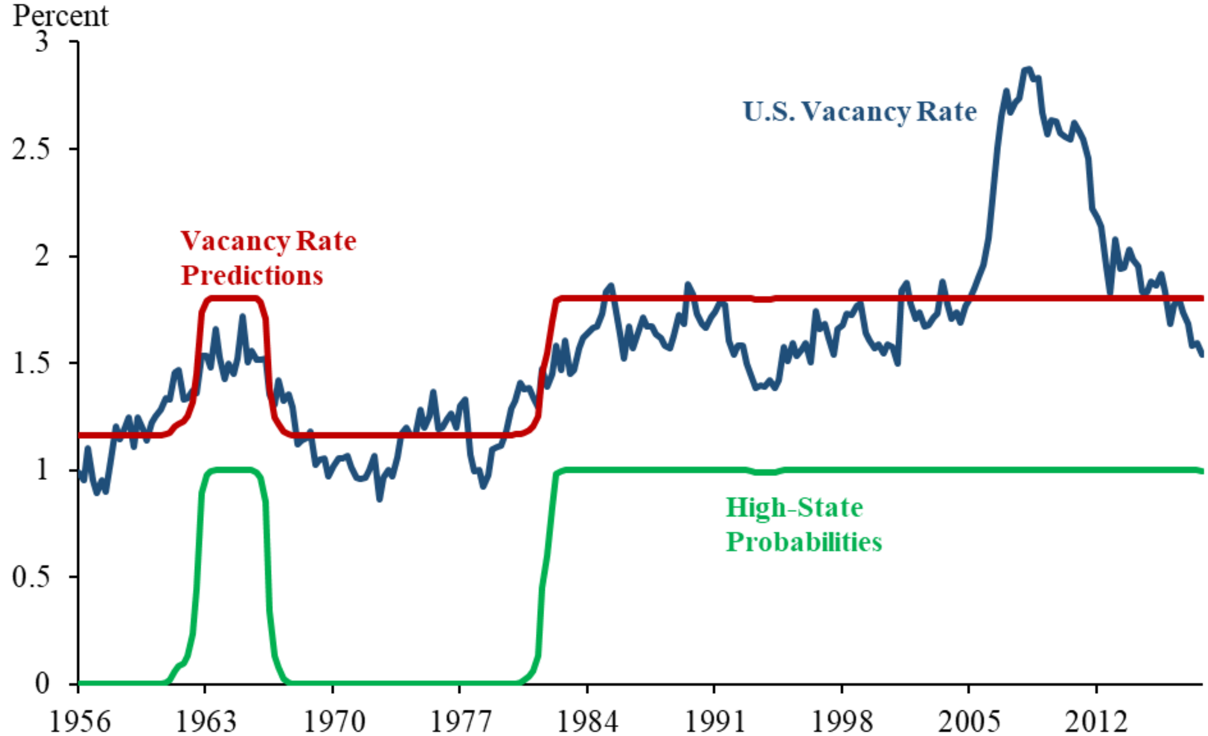


Figure 3

U.S.:Table 1-Based Vacancy Rate Predictions and High-State Probabilities



Sources: Census Bureau/Haver Analytics and Authors' Calculations

Figure 4

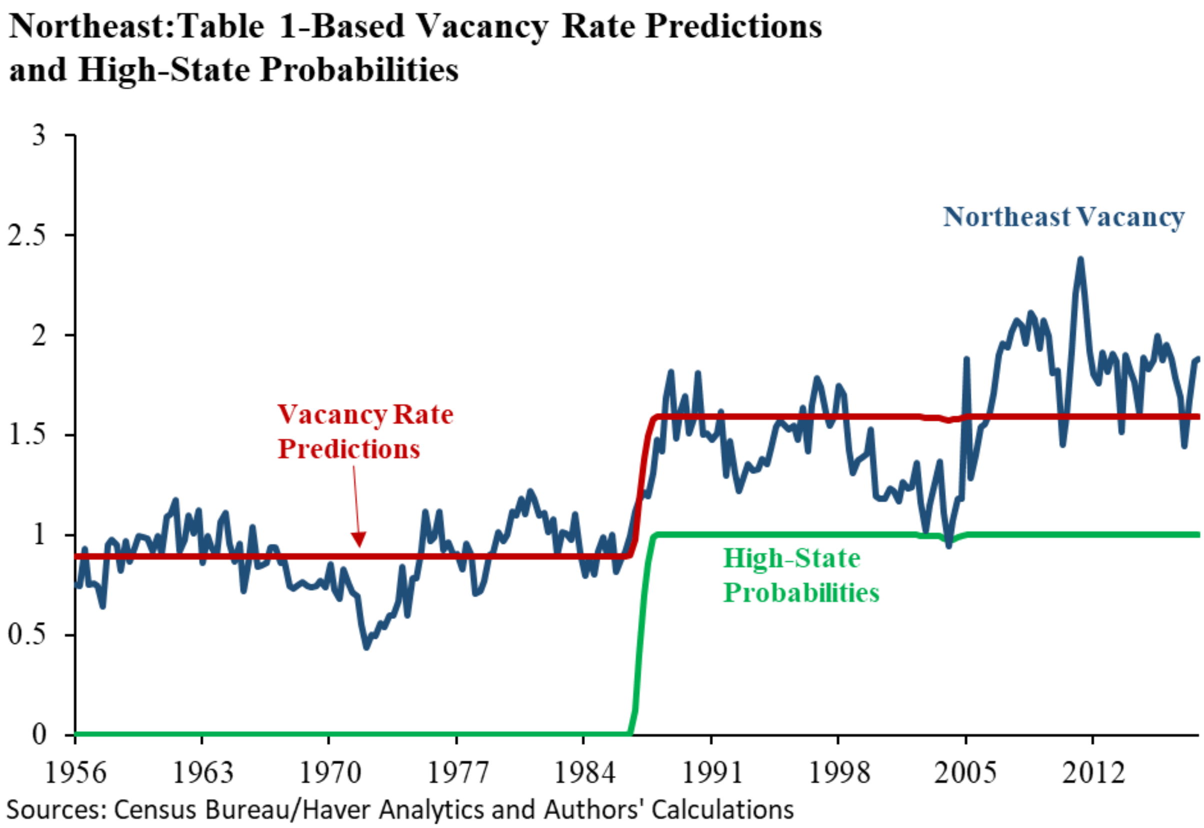

Northeast:Table 1-Based Vacancy Rate Predictions and High-State Probabilities
3
2.5
2
1.5
1
0.5
0
1956
1963
1970
1977
1984
1991
1998
2005
2012
Northeast Vacancy
Vacancy Rate Predictions
High-State Probabilities
Sources: Census Bureau/Haver Analytics and Authors' Calculations

Figure 5

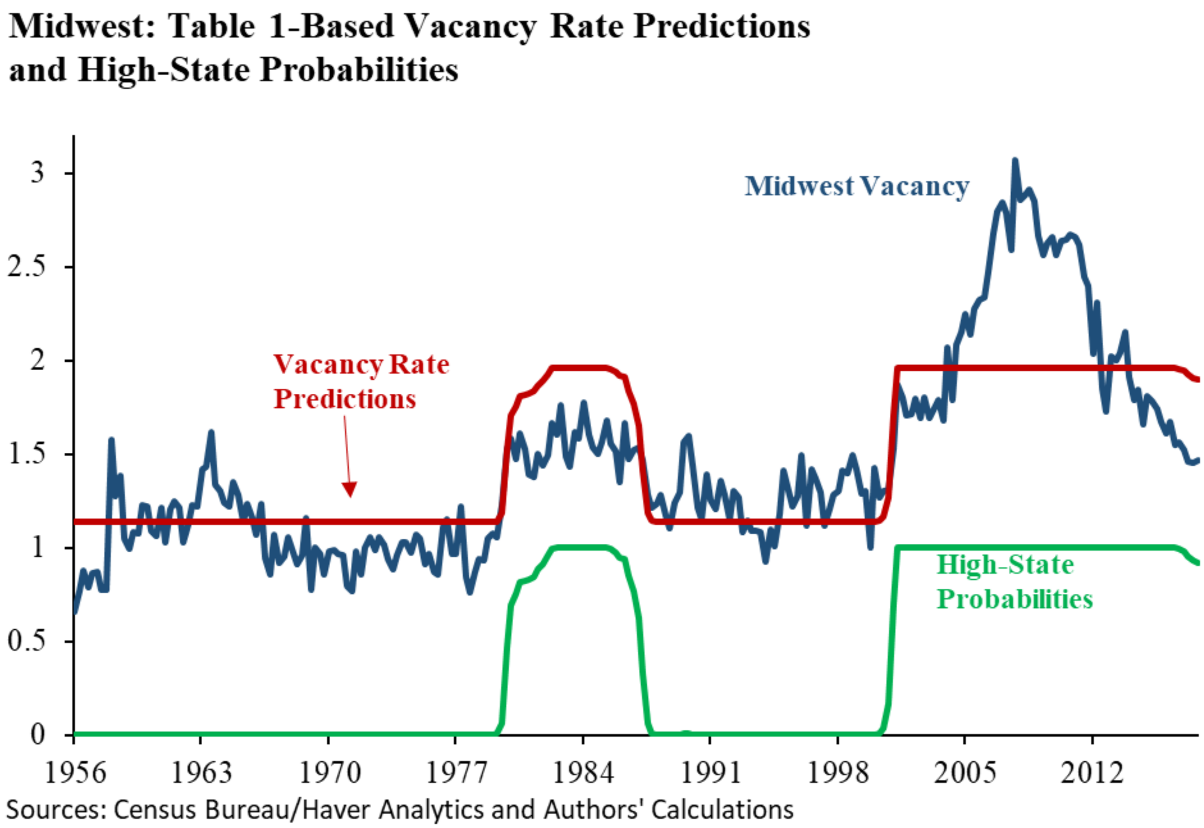

Midwest: Table 1-Based Vacancy Rate Predictions
and High-State Probabilities
Midwest Vacancy
Vacancy Rate
Predictions
High-State
Probabilities
3
2.5
2
1.5
1
0.5
0
1956
1963
1970
1977
1984
1991
1998
2005
2012
Sources: Census Bureau/Haver Analytics and Authors' Calculations

Figure 6

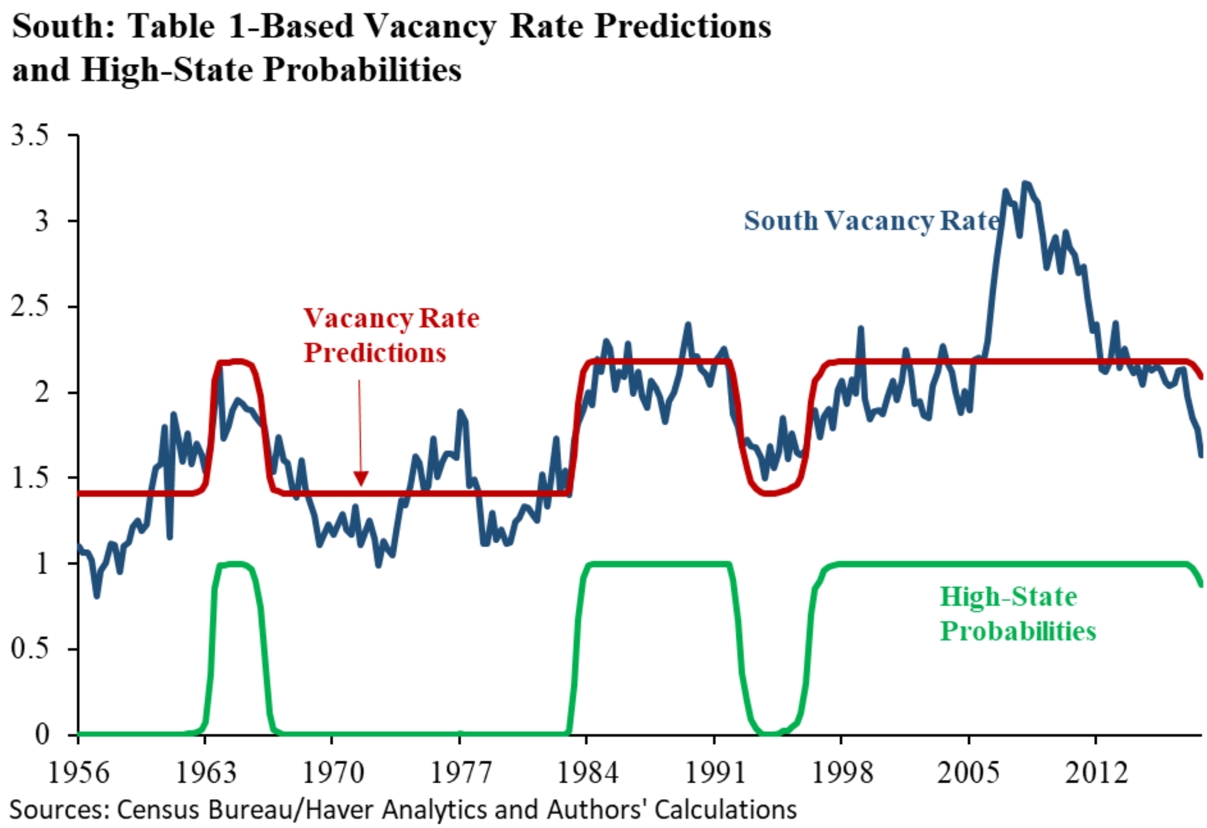
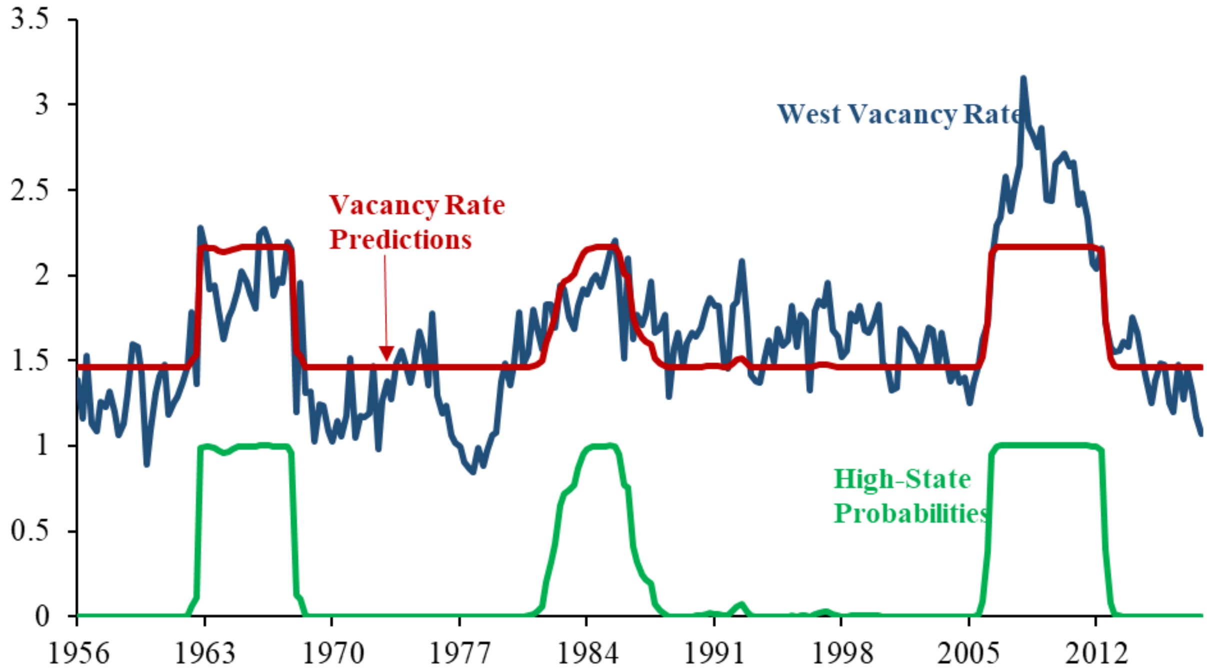

South: Table 1-Based Vacancy Rate Predictions
and High-State Probabilities
3.5
3
2.5
2
1.5
1
0.5
0
1956
1963
1970
1977
1984
1991
1998
2005
2012
South Vacancy Rate
Vacancy Rate
Predictions
High-State
Probabilities
Sources: Census Bureau/Haver Analytics and Authors' Calculations

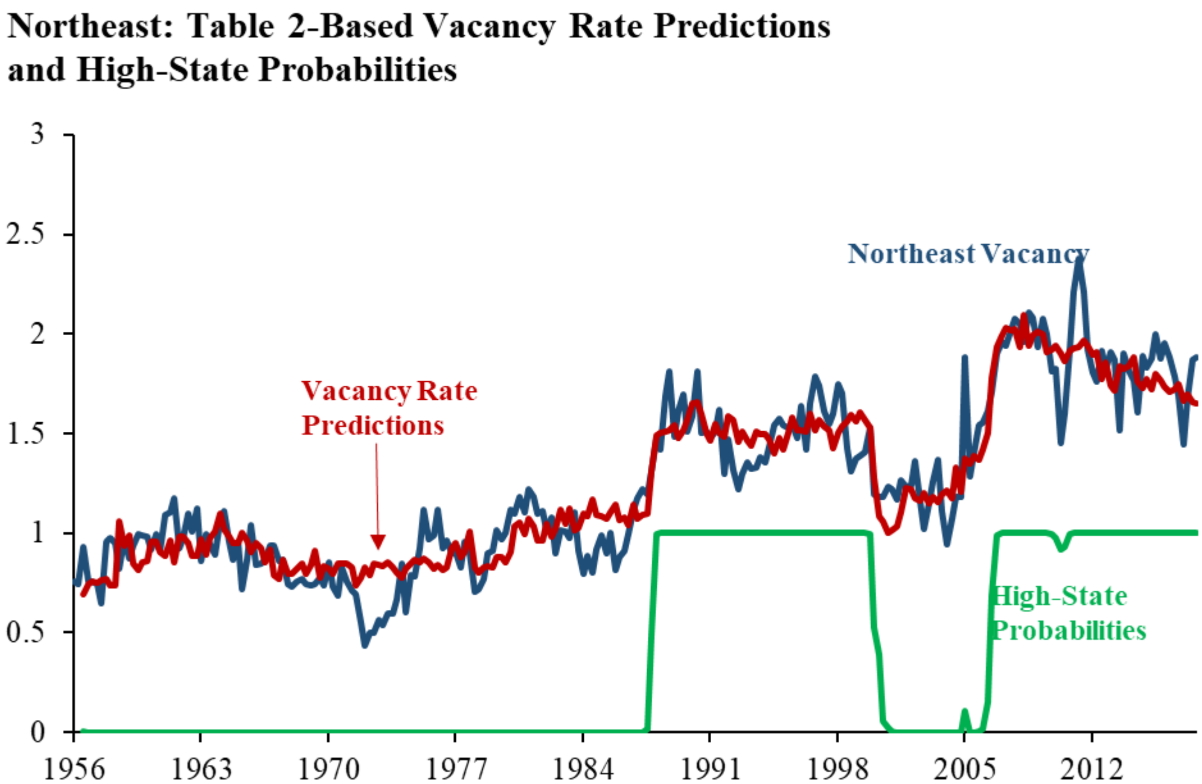
Figure 7

West: Table 1-Based Vacancy Rate Predictions and High-State Probabilities



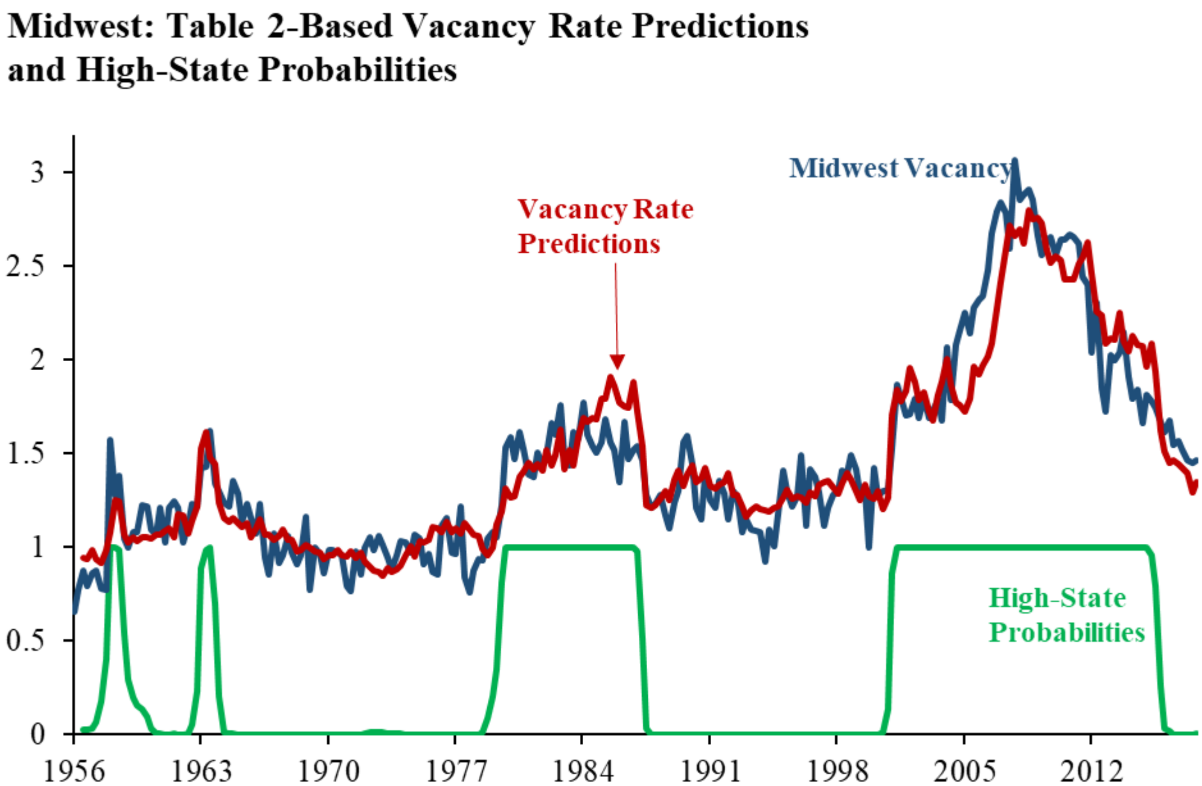
Sources: Census Bureau/Haver Analytics and Authors' Calculations

Figure 8



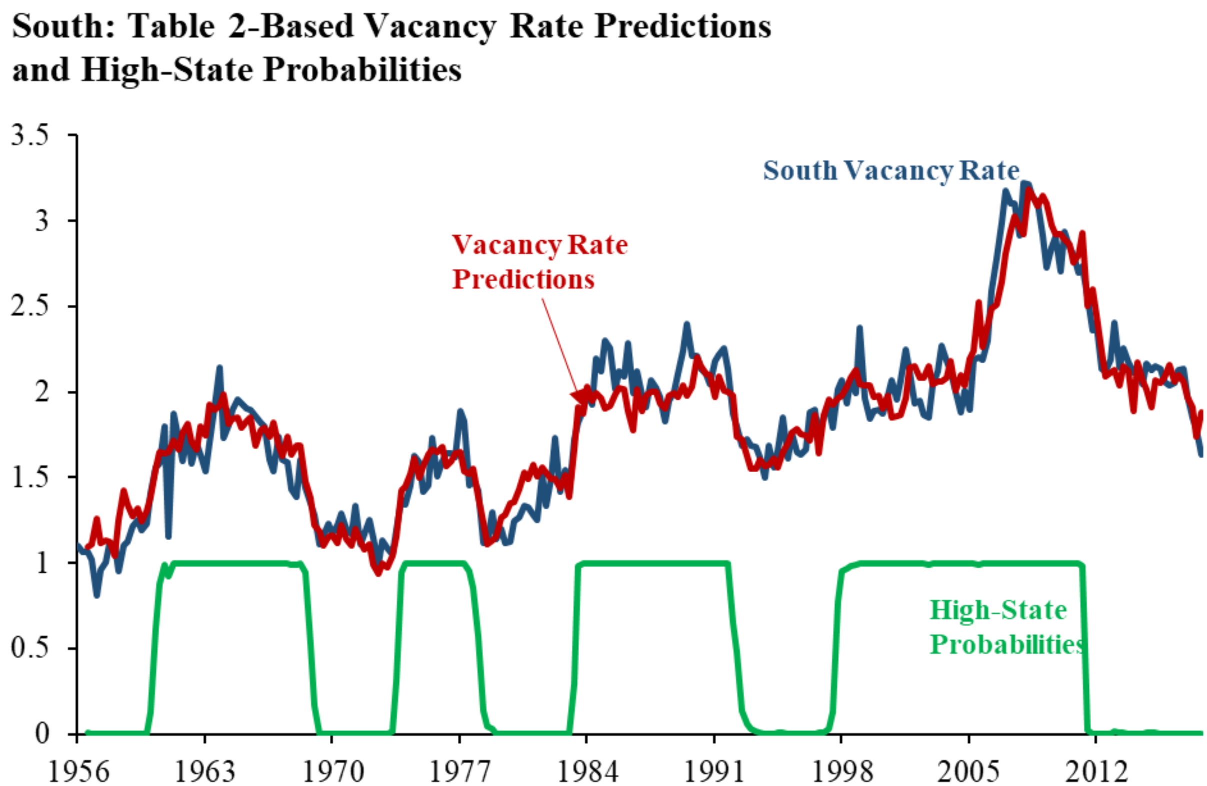
Sources: Census Bureau/Haver Analytics and Authors' Calculations

Figure 9



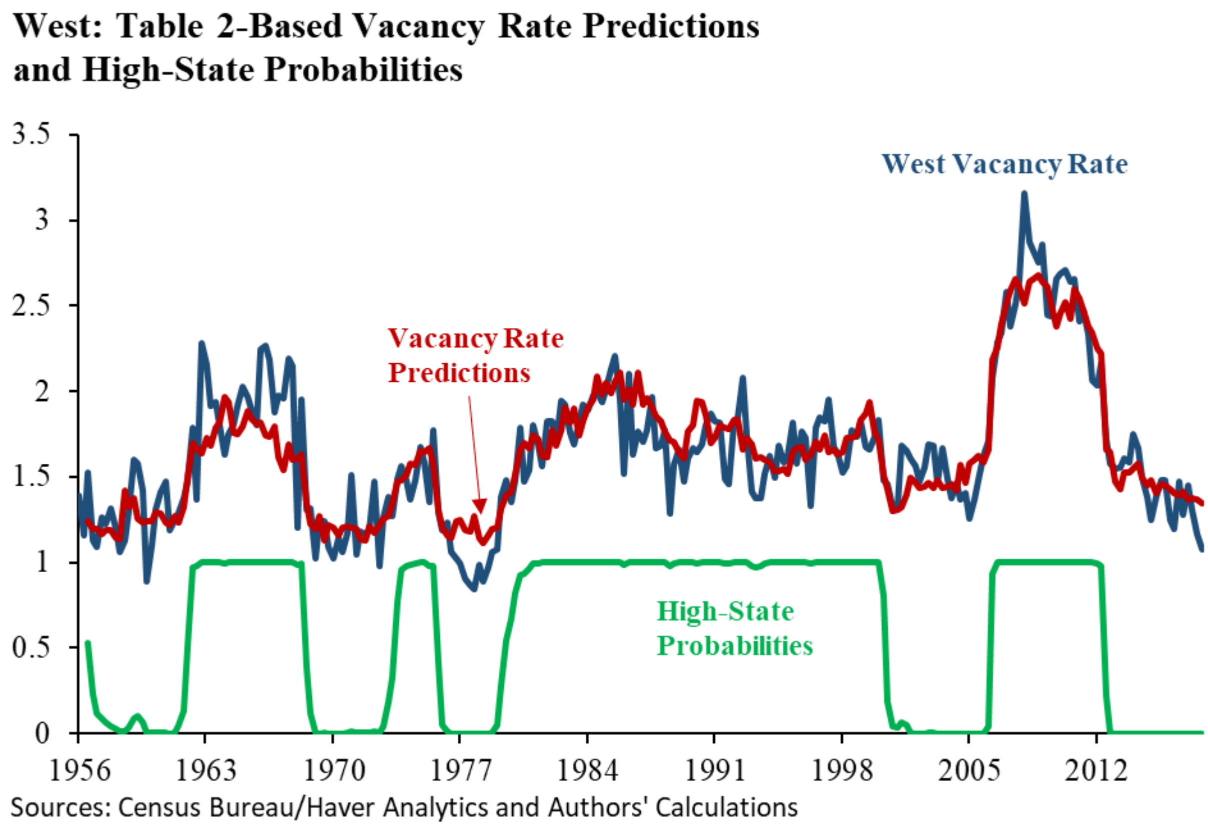
Sources: Census Bureau/Haver Analytics and Authors' Calculations

Figure 10



Sources: Census Bureau/Haver Analytics and Authors' Calculations

Figure 11


West: Table 2-Based Vacancy Rate Predictions
and High-State Probabilities
3.5
3
2.5
2
1.5
1
0.5
0
West Vacancy Rate
Vacancy Rate
Predictions
High-State
Probabilities
1956
1963
1970
1977
1984
1991
1998
2005
2012
Sources: Census Bureau/Haver Analytics and Authors' Calculations

Appendix:

Markov-switching Models and Vacancy Rates

Some time series variables exhibit changes in behavior from one stretch of time to the next. For an example of such a variable, consider a city that has persistent periods of two types of easily distinguished weather - comfortable temperatures and heat waves. Daily construction activity, C, in a non-heat wave period at time t is described as $C_t = \beta_0 + \alpha_0'(Z_t)$, where β_0 and α_0 are respectively a constant and a coefficient column vector, both being specific to comfortable days. Z_t is a column vector of explanatory variables at time t. Meanwhile, construction activity during heat waves could be described as $C_t = \beta_1 + \alpha_1'(Z_t)$. It is reasonable to believe that, ceteris paribus, the former equation will predict much higher construction activity than the latter. Further, assuming we have all the data for independent variables and daily construction activity, estimation of these equations is relatively straightforward because we can distinguish whether past days were in a heat wave, and then estimate each equation using appropriate data.

Unfortunately, it is frequently difficult to distinguish between variables' different behaviors, which can be thought of as belonging to different states or regimes. Consider U.S. labor productivity growth, which likely goes through periods of low growth and high growth. We do not have any binary indicators that tell us when some shock has, for example, shifted labor productivity to a low-growth state. Such shocks are random and difficult to spot even after they have occurred. Markov-switching models, first discussed in Hamilton (1989) and further detailed in Hamilton (1994), attempt to deal with this problem of having a variable characterized by different states that have no simple way of being identified. That is, Markov-switching models attempt to identify unobservable states of the world, and describe how variables behave in each state. "Markov" refers to the fact that the models use Markov chains to characterize the unobserved states.

Markov-switching models have been used in a variety of applications. Billio et al. (2016) and Hamilton and Owyang (2012) use the models to compare business cycles across countries and states, respectively. Cermeño (2002) uses a simple Markov-switching model to characterize low-growth and high-growth regimes for per capita output of U.S. states and several countries. Ihle, Cramon-Taubadel, and Zorel (2009) use a Markov-switching model to characterize the transmission of maize prices between two African countries.

A general Markov-switching model, with dependent variable at time t, y_t, and column vector of explanatory variables, possibly including lags of y, at time t, X_t, is:

$$y_t = \beta_{s_t} + \alpha'_{s_t}(X_t) + \varepsilon_t, \tag{23}$$

where s_t, derived through estimation of a Markov chain, indicates the state of y at time t, and $\varepsilon_t \sim$ i.i.d. $N(0, \sigma_{s_t}^2)$.[17] Thus, the variance of the error term, the value of the constant, β, and the coefficient column vector, α, can depend on s_t. It is not required that all parameters depend on the regime, but at least one must or (13) would become a simple regression. Note that if X contains no variables, (13) is reduced to a constant-only model where the constant for each regime will simply be the regime's average value for y.

There is also an explicit autoregressive Markov-switching model, thoroughly described in Hamilton (1994):

$$(24)\quad y_t = \beta_{s_t} + \alpha'_{s_t}(X_t) + \gamma^1_{s_t}\left(y_{t-1} - \beta_{s_{t-1}} - \alpha'_{s_{t-1}}(X_{t-1})\right) + \gamma^2_{s_t}\left(y_{t-2} - \beta_{s_{t-2}} - \alpha'_{s_{t-2}}(X_{t-2})\right) + \cdots + \varepsilon_t,$$

where $\gamma^1_{s_t}, \gamma^2_{s_t}, \ldots$ are the coefficients for the differences between the first, second,… lag terms and their estimates less autoregressive terms, and all other parameters and variables are as described above. Similar to the other parameters, the γ's can, but do not have to, depend on the regime.

[17] The inclusion of autoregressive variables tends to produce smoother regime changes. Models without autoregressive variables tends to generate abrupt switches.