2013 V41 3: pp. 449–480
DOI: 10.1111/reec.12009
REAL ESTATE
ECONOMICS

Evidence and Implications of Regime Shifts: Time-Varying Effects of the United States and Japanese Economies on House Prices in Hawaii

John Krainer* and James A. Wilcox**

We show that local house prices may be driven almost entirely by the demands of one identifiable group for several years and then by demands of another group at other times. We present evidence that house prices in Hawaii were subject to such regime shifts. Prices responded to demands associated with U.S. incomes and wealth for most years from 1975 through 2008. For about a decade starting in the middle of the 1980s, after the Japanese yen appreciated dramatically and Japanese housing and stock market wealth soared, however, house prices in Hawaii responded to Japanese incomes and wealth. Estimated models with these regime shifts outperformed conventional, constant-coefficient models. The regime-shifting model helps explain why, when and by how much the volatility and the elasticities of house prices in Hawaii with respect to the incomes and wealth of the United States and Japan varied over time.

We investigate the oft-made observations of real estate professionals that, in some places and times, house prices appear to be driven largely by the demands of one identifiable group of buyers, whose effects on prices often arise abruptly, prevail for a time and then vanish (see, *e.g.*, Lindsey 1988). Our study provides evidence that house prices in Hawaii over recent decades fit that pattern.

We find that a regime-shifting model, which estimates for each year whether U.S. demands or Japanese demands but not both, better accounts for house prices in Hawaii than does a conventional model, which imposes constant coefficients on U.S. and on Japanese demands. Estimates of the regime-shifting model imply that only U.S. demands affected house prices in Hawaii during the years 1975–2008, except for the Japanese "regime," which we estimated to run

*Federal Reserve Bank of San Francisco, San Francisco, CA 94105 or john.krainer@sf.frb.org.
**Lowrey Professor of Financial Institutions, Haas School of Business, University of California, Berkeley, Berkeley, CA 94720 or jwilcox@haas.berkeley.edu.

from the mid-1980s through the mid-1990s. Because the market reflected only Japanese demands then, prices were driven by Japanese incomes and wealth and their associated elasticities. During the Japanese regime, the implied effects of U.S. incomes, wealth and elasticities on house prices in Hawaii were zero. In the U.S. regime, the roles were reversed. Prices were driven by U.S. demand to the virtual exclusion of effects of Japanese demand.

Why might the effects on house prices of one group's demands rise and fall so far so fast? If houses can be regarded, in effect, as being sold via auctions, then their sales prices reflect the demands of the highest bidders, but not the demands of the lower bidders. When enough of the winning bidders come from one identifiable (the "first") group for a time, house prices are in a "regime" where only the first group's demands affect prices. The winning bids from the first group will affect the sales prices of many houses directly. Because of the partial substitutability of houses, the higher demands of the first group can also indirectly raise the sales prices of many other houses, which are purchased by those in the second group and by Hawaiians.[1]

While in the first group's regime, prices change commensurately with the first group's incomes, wealth, elasticities and any other variables that affect their demands. If the second group's incomes and wealth rise sufficiently, then the second group's share of winning bids can rise dramatically. So can its effects on prices. After shifting to a regime dominated by the second group, prices will be determined by the wealth and other determinants of demand and the elasticities of this other group. As a market shifts to the second regime, the effects of the first group's demands on prices shift to zero. Regime shifts then can be a source of time-varying effects or coefficients.

After a market shifts regimes, prices then (but not before the regime shift) reflect the demands of the group who became the highest bidders. In the new regime, demands from the group that formerly had the highest bidders no longer affect prices. That is, the effects on prices, or coefficients, of demand of one group rise abruptly and the coefficients of the other group fall abruptly.

Regime shifts can also be a source of time-varying volatility of prices (and other variables) and of the volatility of their unaccounted-for movements. The volatility of prices depends on the interaction of the volatility of demand determinants with their associated elasticities. The volatilities of the determinants

[1] Our discussion, model and empirical analysis consider only two groups. In principle, regimes might shift among many groups. We considered but ruled out the possibility of a Canadian regime because, through the end of our sample period in 2008, Canadians made very few visits to Hawaii relative to visitors from the mainland United States or Japan.

of demands may differ considerably across groups. For example, the wealth of one group may be more volatile than that of the other group. In addition, demand elasticities may differ by group. Responses of demand to changes in incomes and interest rates, for example, may be smaller for a higher-saving group. Regime shifts then can translate into time-varying variances of prices and of any other endogenous variables. Differences across groups in measured determinants are likely to be complemented by differences in unmeasured determinants. If so, then regime shifts can also produce heteroskedasticity in the unaccounted-for movements of prices and other variables. Thus, regime shifts imply that neither coefficients nor volatilities will be constant over time.

This article is organized as follows. In the next section we sketch out an auction-based model of house prices with two groups of bidders. Our model explains how a group's share of the sales of houses can fluctuate dramatically, even when its relative income or wealth changes only moderately. The third section discusses some of the special features of Hawaii. In the fourth section, we present a constant-coefficient, reduced-form model of house prices in Hawaii that serves as benchmark. The fifth section describes the selection and construction of the variables that we used. The sixth section presents estimates of several specifications of the benchmark model, which imposes weights on the demands from the Unites States and from Japan that do not vary over time. We demonstrate in the seventh section that, despite their successes, the benchmark models generally exhibit considerable coefficient instability.

The eighth section explains how we estimated our regime-shifting model. By various criteria, we show that the estimated regime-shifting model significantly outperforms the benchmark model. In the ninth section, we summarize our findings and argue that regime shifts might account for effects and volatilities in other times and in other markets that are time-varying.

Determining House Prices via Auctions

This section begins by describing briefly features of the demand for and supply of houses in Hawaii that led us to use an auction-based model to explain their prices. We consider the effects on prices of the demands from two groups of potential bidders. Our model implies that the share of houses sold to the first group rises highly nonlinearly with the relative demand of the first group. The model shows that the share can rise dramatically (or negligibly) when the first group's demand, relative to that of the second group, rises only moderately. The model further implies the marginal effect of the first group's demand on prices is proportional to its market share. Thus, the effect of, and regression coefficient on, each group's demand varies nonlinearly with its demand relative to the demand of the other group.

Uncertainties and Auctions

The market for houses in Hawaii has some features of auction markets and has, perhaps, more similarities than most markets for houses. Individual houses in Hawaii (and elsewhere) are indivisible goods and have only imperfect substitutes. In that regard, they are like objects of fine art, but are unlike a barrel of oil or a bushel of wheat, each of which have prices that are not posted but that are essentially determined by auctions. In many auctions, supply is predetermined. As we detail below, the supply of houses in Hawaii is severely constrained both by nature and by man.

Given who buys houses in Hawaii, we contend that bidders from the United States and from Japan for houses in Hawaii have relatively large incomes and wealth and have large income and wealth elasticities of demand. We observe that owners and even visitors to Hawaii are skewed toward higher incomes and wealth. Later, we provide some evidence that elasticities of demand with respect to income and wealth are quite high. It would generally be uncontroversial to use a house in Hawaii as an example of a "luxury good." Households with higher incomes, in part because of their high effective correlations with capital market incomes, may well also have more volatile and more uncertain incomes and wealth (see Parker and Vissing-Jorgensen 2010).

The combination of uncertain incomes and wealth over time and large elasticities can make individual demands for houses in Hawaii quite uncertain over time. Another source of demand uncertainty likely stems from the incomes, wealth and availability of imperfectly substitutable alternative (vacation) houses of offshore bidders being heavily dependent on the (mainland) United States and on the Japanese economies, which are very distant and very different from the economy of Hawaii. Coupled with the low elasticity of supply, uncertain (*i.e.*, unpredictable) demands can create significant uncertainties about the market clearing prices of houses, and especially of individual houses. One way that markets sometimes resolve significant uncertainties about market-clearing prices is to conduct auctions. Thus, we regard there being good reasons for houses to be sold as if by auctions and we regard (sealed-bid) auctions as satisfactory approximations to the actual sales mechanisms for houses in Hawaii.

We assume that there are enough bidders to rule out effective price collusion. We assume that bidders are all equally well informed. We assume that, for each house, each bidder has a reservation value, which is the maximum amount that bidder is willing to pay for that house. The maximum amount depends on the bidder's preferences for the attributes of each house and the bidder's ability to pay. We take the bidder's income or wealth to indicate ability to pay. Because bidders differ by preferences and by ability to pay, reservation values differ by bidder.

Bidding, Prices and Market Shares

The optimal strategy in sealed-bid auctions with sufficient, equally informed bidders is to bid one's reservation value.[2] To simplify our model, we assume that each bidder j (from the United States or Japan, as denoted by the US and JP superscripts) has Cobb–Douglas preferences. We denote the number of bidders from the United States as J^{US}; the number of bidders from Japan is J^{JP}. Cobb–Douglas preferences imply that each bidder has a reservation value for each house at each time t, RV_{ijt}, that is proportional to the bidder's wealth at time t, W_{jt}:

$$RV_{ij^{US}t} = \eta_{ij^{US}} W_{j^{US}t} \quad \text{and} \quad RV_{ij^{JP}t} = \eta_{ij^{JP}} W_{j^{JP}t}. \tag{1}$$

For each bidder, that proportion, η_{ij}, varies across houses due to differences across houses in their attributes, but it does not vary over time. For a particular house, that proportion, η_{ij}, also varies across bidders due to differences in their preferences.

Each seller is uncertain about, P_{it}, the eventual sales price. Uncertainty about P_{it} can result from sellers' uncertainties about (1) how many people from each country, J^{US} and J^{JP} will bid, (2) what the values of the proportions, η_{ij}, are for each bidder for each house and (3) what the bidders' individual wealth, W_{jt}, is. As noted above, such uncertainties often lead to auctions.

Eventually, each house i will be sold at time t to the highest bidder at a price, P_{it}, regardless of which country (the United States or Japan) the bidder comes from:

$$P_{it} = \max[RV_{i1t}, \ldots, RV_{ij^{US}t}, RV_{i1t}, \ldots, RV_{ij^{JP}t}]. \tag{2}$$

The probability, s_{it}, that the maximum bid is made by a Japanese bidder is:

$$s_{it} = \Pr(\max[RV_{i1t}, \ldots, RV_{ij^{JP}t}] > \max[RV_{i1t}, \ldots, RV_{ij^{US}t}]). \tag{3}$$

[2]In practice, the selling process for houses may be more akin to ascending bid auctions.

Equations (2) and (3) imply that the expected sales price for house i is given by Equation (4), which weights the expected maximum bid from each country by the probability that bid would be the winning bid:[3]

$$E(P_{it}) = (1 - s_{it}) \max[RV_{i1t}, \ldots, RV_{ij^{US}t}] + s_{it} \max[RV_{i1t}, \ldots, RV_{ij^{JP}t}]. \quad (4)$$

We assume that the expected maximum bid from each country at any time can be reasonably approximated by a linear function of that country's wealth. The stronger the preferences for houses in Hawaii, the larger we would expect the coefficients in Equation (5). Then, for Japan, and analogously for the United States, the expected maximum bid is given by:

$$E(\max[RV_{i1t}, \ldots, RV_{ij^{JP}t}]) \approx \alpha_0^{JP} + \alpha_1^{JP} W_t^{JP}, \quad (5)$$

where W_t^{JP} is the national wealth of Japan.

The actual prices of houses sold at any time differ from their expected prices because the actual winning bids can differ from the expected winning bids implied by Equation (5). We can collect the difference between the actual and expected price of a house into a disturbance term, e_{it}, as shown in Equation (6):

$$P_{it} = E(P_{it}) + e_{it}. \quad (6)$$

The actual and expected prices of house i inevitably differ because Equation (5), which contains only one national indicator, does not include all of the factors that affect the expected winning bids. Differences also arise because Equation (5) omits any information that is specific to house i or that pertains to individual bidders in the two countries. As a result, the disturbance term, e_{it}, is a composite of the omitted effects associated with either country. The variance of e_{it} then also would incorporate the variance of the omitted effects from each country.

Substituting Equation (5) from the United States and Japan and Equation (4) into Equation (6) and averaging over the I houses sold during time t produces the equation for the average price of houses:

$$\frac{1}{I}\sum_i P_{it} = \frac{1}{I}\sum_i \left((1 - s_{it})\left(\alpha_0^{US} + \alpha_1^{US} W_t^{US}\right) + s_{it}\left(\alpha_0^{JP} + \alpha_1^{JP} W_t^{JP}\right) + e_{it}\right). \quad (7)$$

[3]Based on their expectations for P_{it}, sellers may declare (nonbinding) listing prices for their houses before the auctions take place. Listing prices may typically and deliberately be set above the prices that sellers expect to receive.

We denote the average price from Equation (7) as P_t and the average during time t of e_{it} as e_t.[4] We interpret s_t, the average over I of the probabilities that the highest bidder is Japanese, as the Japanese share of purchases. Equation (8) shows that the average price depends on the Japanese share of purchases and the wealth of the United States and of Japan:

$$P_t = (1 - s_t)\left(\alpha_0^{US} + \alpha_1^{US} W_t^{US}\right) + s_t\left(\alpha_0^{JP} + \alpha_1^{JP} W_t^{JP}\right) + e_t. \tag{8}$$

Equation (8) shows that the effect of a country's wealth on the average price at any time t varies positively with the strength of that country's preferences for houses in Hawaii and with its share of purchases. Equation (8) also shows that a rise in the Japanese share, s_t, reduces the effect of U.S. wealth at the same time that it raises the effect of Japanese wealth, and vice versa. Next we show how the distribution of preferences and shifts in the relative wealth of two countries interact. In particular, we show that the effect of, or coefficient on, a country's wealth can shift dramatically, even if relative wealth changes only moderately.

Skewness of Reservation Values

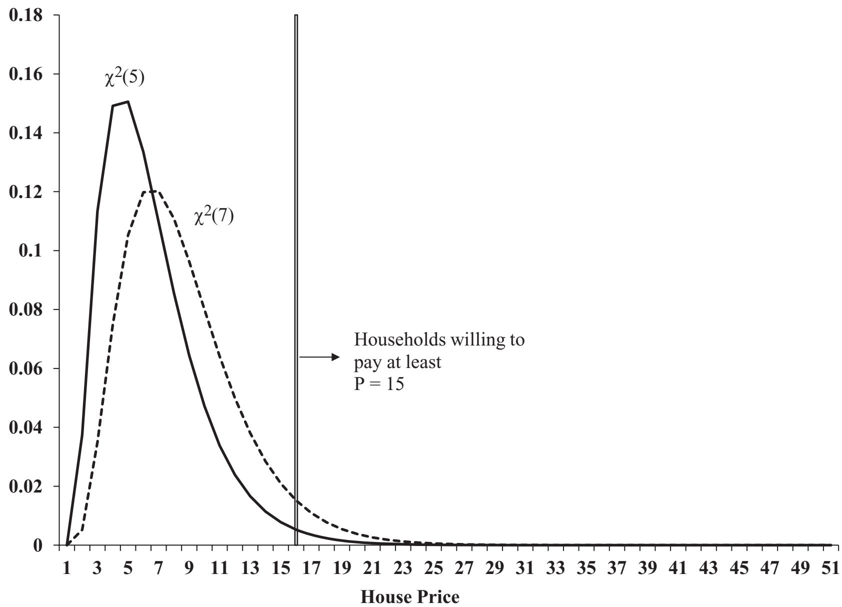
Figure 1 shows distributions of reservation values within a country that are skewed to the right. There we depict reservation values that are distributed as chi-squares. The solid line shows a chi-square distribution that has a mean equal to five; the dashed line shows a chi-square distribution that has a mean equal to seven, which implies a more skewed distribution. The vertical line is drawn at a house price equal to 15. The areas under the two distributions show the share of bidders whose reservation values are larger than 15. Figure 1 then shows how skewness adds higher bidders. In Figure 1, for any house price above (approximately) seven, a larger share of bidders from the more skewed distribution has reservation values that are larger than the house price.

One reason that reservation values are likely to be skewed to the right is that distributions of individual incomes and wealth within most countries are skewed to the right. The distribution of preferences is also very likely skewed rightward, as evidenced by some households' being willing to spend far more of their incomes or wealth on houses in Hawaii than others are. Any skewness of preferences for houses in Hawaii, thereby, adds to the skewness of the distributions of reservation values that would arise from skewed income and wealth distributions.[5]

[4]We expect that e_t would average zero over enough time periods. At any given time t, however, even though it is averaged over I houses sold, there is no reason to expect e_t to be zero in each period.

[5]Including idiosyncratic preferences for houses in Hawaii reduces the odds that only the wealthiest households buy houses in Hawaii. Some of the wealthiest households,

Figure 1 ■ Skewed distributions of reservation values for houses.



Note: The figure plots two chi-square distributions of reservation values for a particular house. One distribution has a mean of five (solid line) and the other one has a mean of seven (dashed line). The area that is under each distribution and is to the right of the vertical line drawn at a house price of 15 indicates the share of potential buyers whose reservation values, and thus willingness to pay, exceed 15 for that house.

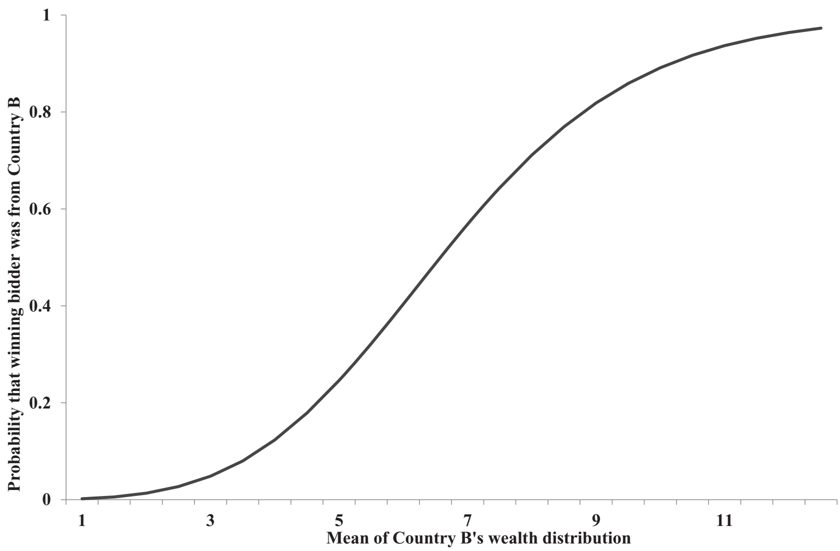
Shifts in the relative wealth of two countries change the probability for each country that the maximum (winning) bid for a house comes from that country. Separately, a widespread increase in the preferences or in the skewness of preferences in a country for houses in Hawaii would also increase the reservation values and resulting probabilities.

Shifting Wealth and Market Shares

Figure 2 illustrates how the probability that the winning bid comes from Country B rises as Country B's wealth rises. To highlight the effects of relative wealth on the calculated probabilities in Figure 2, we made reservation values for each individual in each country the same proportion of each individual's wealth. We assume that wealth in Country A has a chi-squared distribution with a mean

for example, may not much value a house in Hawaii. Some of them also likely prefer consumption that does not require such high costs of travel time.

Figure 2 ■ Probability of winning bidder coming from Country B as function of Country B wealth.



Note: The figure shows the probabilities that a bidder from Country B wins an auction for a house. We consider bidders from each of two countries, A and B. Each bidder from each country is assumed to make a bid that is proportional to the bidder's wealth. Each probability is based on 100 bids from Country A and 50 bids from Country B. The bids are based on random draws from the wealth distribution of each country. We assumed that wealth in Country A was distributed as chi-square with a mean of five. Wealth in Country B is also distributed as chi-square. The probabilities that the winning bidder was from Country B rise as the mean of the chi-square distribution of Country B's wealth rises from 0.25 to 12.

equal to five, *i.e.*, $\chi^2(5)$. To show how relative wealth affects the probabilities, and thus the market shares, we calculated the probability for a range of values of the mean of the chi-squared distribution of wealth in Country B from 0.25 to 12. The population of the United States is about double that of Japan. The total numbers of actual and potential bidders for each house typically might be quite large. Therefore, Figure 2 presents the probabilities that would be implied by 100 random draws from the wealth (and thus reservation value) distribution of Country A and 50 random draws from the wealth distribution of Country B.[6] Figure 2 shows that, even when the means of the wealth distributions of the two countries A and B are equal to five, having fewer bidders implies that the

[6]We take the realized frequencies from 1,000 replications of 150 draws for each level of wealth in Country B as estimates of the probabilities.

probability of the winning bid coming from Country B is noticeably less than 0.50.

The probabilities of a winning bid coming from Country B trace out an S-shape as the wealth of Country B rises. The probabilities change most dramatically when the mean of Country B's wealth, and thus its reservation values, is closer to Country A's mean. If Country B's wealth rises enough relative to the A's wealth, the probabilities of a bidder from B winning each house auction asymptotically approaches 1.00 (*i.e.*, 100%). Similarly, a country whose bidders had preferences for houses in Hawaii that strengthened over time would have increasingly large marginal effects on prices.

The probabilities in Figure 2 also serve as estimates of s_t, the share of all houses sold to bidders from Country B. Thus, Figure 2 shows how considerably the share, which Equation (8) shows determines the marginal effect of or coefficient on prices of a country's wealth, rises over the range of its (relative) wealth. As Country B's relative wealth ranges from nearly zero to over 10, Figure 2 shows that the probabilities, and thus s_t, rise from nearly zero to 100%, implying that the effects on prices of changes in Country B's wealth range from nearly zero to being nearly the only factor that affects prices.

Below we analyze an especially dramatic shift in coefficients. We analyze whether the shifts in the relative wealth of the United States and Japan have been large enough that the prices of houses in Hawaii acted as if they were determined completely by bidders from the United States for some years, but were completely determined by bidders from Japan for other years. We find evidence that house prices in Hawaii were better accounted for when we allowed for dramatic "regime shifts" of coefficients than when we specified constant (but different) coefficients on the wealth of the United States and Japan.

Hawaii Is Ideal

Demand for Houses in Hawaii

In many ways, the market for houses in Hawaii is an ideal setting for detecting regime shifts. Located nearly in the middle of the Pacific Ocean, Hawaii is 2,500 miles from the United States mainland and 3,800 miles from Tokyo, Japan. The climate, beaches, culture, scenery and entertainment in Hawaii create strong demand for its houses. Two large, identifiable groups dominate the offshore demand for houses in Hawaii, the residents of Japan and the residents of the (mainland) United States. There is no significant source of offshore demand for houses in Hawaii that is nearer than the United States mainland or Japan. The per-capita incomes and wealth of the residents of Hawaii's two closest and important neighbors, the mainland United States and Japan, were also two of the highest in the world.[7] Relative to the populations of the mainland United States and Japan, the number of houses available for sale in Hawaii is small.

The demands of these two groups were not highly correlated in recent decades. Per-capita incomes and wealth in Japan and in the United States were all volatile but not highly correlated with that of the other country over the past three decades. Starting in about 1986, land values and stock prices in Japan began to rise, as did the Japanese yen relative to the U.S. dollar. As a result, Japanese incomes and wealth (in U.S. dollars) rose suddenly and grew rapidly. With the collapse of its asset values and subpar GDP performance in the 1990s, however, Japan suffered a major reversal of fortune and endured a "lost decade" and more. The 1990s were strikingly different for the United States: Real GDP grew rapidly, and, by the late 1990s, the United States had its own asset price boom, with enormous increases in (mainland) real estate and equity values.

Supply of Houses in Hawaii

The supply of houses in Hawaii is constrained by nature and by man. The price-elasticity of the supply of houses in Hawaii is likely to be especially low for two reasons. First, the mountains and the ocean severely limit the amount of potentially buildable land in this small U.S. state. Second, for historical reasons, a very large share of all land in Hawaii is held in public trust or owned by the public sector.[8] Consistent with strong demand and supply that is quite inelastic with respect to house prices, the median house price in Hawaii is about three times the median for the United States as a whole.

The relatively inelastic supply of houses, coupled with the large magnitude, the volatility and the low correlation of demands from the United States and Japan, suggest that house prices in Hawaii might respond strongly to United States, but weakly to Japanese, demand before the years of the Japanese "bubble economy" and after its end. Conversely, prices might have been determined almost completely by demand from Japan during the years of the bubble economy. That is, there may have been regime shifts.

[7] Henceforth we will refer to the mainland United States as simply "the United States."

[8] According to Hintz (1999), 42% of the land is owned by federal, state or city governments. An additional 47% is owned by a few individuals.

Endogeneity of Local Demand for Houses

Hawaiian residents own and buy more houses in Hawaii than the two large groups of offshore demanders do.[9] Thus we need to consider their role in the demand for houses in Hawaii.

Hawaii is not only geographically distinct, but it is also economically distinct. Of the 50 states, Hawaii's economic activity is among the least correlated with aggregate U.S. economic activity. One reason for the lack of correlation is that the Hawaiian economy's sectoral composition differs considerably from that of the mainland U.S. economy and from the economy of Japan. At the end of 2006, for example, the share of employment in manufacturing was less than 3% in Hawaii, while manufacturing accounted for 10% of total U.S. employment and 18% of total Japanese employment. While 17% of Hawaiian employees worked in the leisure and hospitality sector, only 10% of U.S. employees and 5% of Japanese employees worked in that sector.[10] Although Hawaiian per-capita incomes were similar to those in the rest of the United States at about $35,000 in 2005, Hawaiian residents had homeownership rates in 2005 that were only about 60%, compared with 69% in the United States.

Thus, Hawaiian incomes and wealth are unusually dependent, directly and indirectly, on the leisure and hospitality sector. Stronger demand in that sector directly raises many Hawaiians' incomes and wealth, which ripples generally across the Hawaiian economy and population. Therefore, we took the reservation values fueled by incomes and wealth, or demand, for houses by Hawaiian residents to be primarily determined endogenously by demand for the output of the leisure and hospitality sector, which in turn was driven primarily by visitors from Japan and the United States. Their visits and expenditures while there, in turn, were driven by the conditions in the distant, U.S. and Japanese economies. Because it was endogenous, local, Hawaiian demand for houses was incorporated into but did not appear directly in the reduced forms for house prices that we develop further below.

[9] Based on population of a little over one million in Hawaii, its homeownership rate, and the number of houses, we can estimate the share of houses that are owned by Hawaiian residents. Miller, Sklarz, and Ordway (1988) estimated that, at the peak of Japanese demand, Japanese buyers accounted for about 30% of total sales of houses in Hawaii in 1989.

[10] The U.S. and Hawaiian statistics are from December 2006, using the 2005 benchmark. The Japanese labor statistics are from 2005 (http://www.stat.go.jp/english/data/figures/index.htm#o). The estimates for employment in the Japanese leisure and hospitality sector are from employment in the "eating and drinking places, and accommodations" sectors.

Reverberations of Concentrated Demand

Even if they were concentrated near the perimeter of the Hawaiian islands, offshore demands could affect not just house prices on the perimeter but also the prices of many more houses in the geographically small state of Hawaii. The urban structure model of Capozza and Helsley (1990) shows that the house price-distance gradient reflects the costs associated with physical distance. In the usual case, property prices decline monotonically with distance from an urban employment center. The Hawaiian analog to the urban center is perhaps the beach. Indeed, many very-high-priced houses are not near the urban center, but instead are near the perimeters of the islands. The houses that sit along a distance-to-the-beach gradient are imperfectly, but somewhat, substitutable. Given the inelastic supply of houses at any given distance from the beach, increased offshore demand for beachfront or any other houses in Hawaii would directly raise the prices of those houses. Those higher prices would then indirectly raise the prices of other, somewhat substitutable houses as the upward shock to perimeter prices reverberated along the price gradient.

A Constant-Coefficient, Reduced-Form Model of House Prices

Before we estimate a regime-shifting model in the next section, here we specify and then estimate a conventional model of house prices that implies reduced-form coefficients that are constant over time. The Peek and Wilcox (1991) model of the supply of and demand for houses is one example of a model that leads to reduced forms whose coefficients are constant over time. They assume that the supply of houses, Q^s, depends positively on the price of houses (P):

$$Q^S = \varphi_0 + \varphi_1 P. \tag{9}$$

When exogenous demand comes from the United States and Japan, the total demand for houses, Q^D, depends positively on the wealth of each country, W^{JP} and W^{US}, and negatively on the price of houses (P). The inverted demand function for houses can then be written as:

$$P = \theta_0 + \theta_1 W^{US} + \theta_2 W^{JP} - \theta_3 Q^D. \tag{10}$$

Equating demand and supply and inserting (9) into (10) produces (11), the reduced form for the price of houses (P):

$$P = \left(\frac{\theta_0 - \theta_3\varphi_0}{1 + \theta_3\varphi_1}\right) + \left(\frac{\theta_2}{1 + \theta_3\varphi_1}\right) W^{US} + \left(\frac{\theta_1}{1 + \theta_3\varphi_1}\right) W^{JP}. \tag{11}$$

Because the supply and demand functions are linear and have parameters, the φs and the βs, that are constant, the reduced form for the price of houses, P, has constant coefficients. The reduced form in (11) can be rewritten in terms of constant reduced-form coefficients as Equation (12):[11]

$$P = \gamma_0 + \gamma_1 W^{US} + \gamma_2 W^{JP}. \quad (12)$$

Data for House Prices and Demand

In this section we describe the selection and construction of house price, wealth and income variables that we use to estimate reduced-form models of the prices of houses in Hawaii.

House Prices in Hawaii, the United States and Japan

Figure 3 shows indexes of house prices in real U.S. dollars for three places: Hawaii, the United States and Japan. For Hawaii and the United States, we used the annual Federal Housing Finance Agency (FHFA) nominal house price indexes.[12] We divided those nominal house prices by the consumer price index for Honolulu and for the United States, respectively, to get the real price of houses in Hawaii and the United States There is no readily available nationwide measure for house prices in Japan for our long sample period.

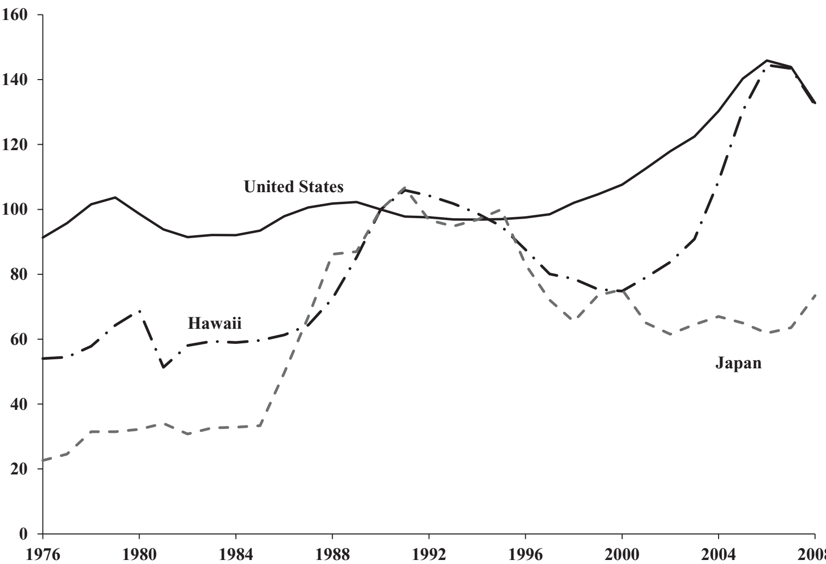
We use prices of land and prices of structures to construct a price index for houses in Japan. First, we calculated an equally weighted average of the prices of land in each prefecture.[13] Next, we assumed that the real price of structures in Japan was constant over our sample period. The more elastic the supply curve is for structures, the less that changes in demand for houses get capitalized in structure prices and the more that they get capitalized into the prices of less-elastically supplied land. We scaled the indexes of land and structure prices so

[11]The linearity of the reduced form here does not depend on whether the variables are expressed in levels or logs or other transformations. Below we specify house prices and wealth in logs. A constant-coefficient reduced form here does require that the same transformation (*e.g.*, linear, log, *etc.*) be applied the quantity of houses in the supply and demand functions.

[12]We made one adjustment to the data for Hawaii, *viz*., for 1981. The year 1981 had unusually high interest and unemployment rates. Nevertheless, we judged the decline of over 50% in the nominal price of houses in Hawaii in the FHFA's repeat-sales price index for 1981 to be too large. Therefore we raised the 1981 value to a level that was halfway between the recorded level (30) and the average (60) of the values of the adjacent years 1980 (70) and 1982 (50); that is, we raised the nominal level from 30 to 45. In real terms, even this upward-adjusted price fell by well over 40% in 1981.

[13]We used data for land prices by prefecture by year from Research on Land Prices by the Prefectural Governments. The data are available online at http://www.stat.go.jp/english/data/nenkan/1431-17.htm.

Figure 3 ■ Indexes of real house prices in Hawaii, in the United States and in Japan, 1975–2008.



Note: Indexes of real house prices in Hawaii, the United States and Japan in U.S. dollars. Each index was based to equal 100 in 1990.

that the value of Japanese houses in 1976 consisted of equal values of land and of structures. Then, we added the scaled Japanese real land and real structure prices to form the index of real house (land plus structures) prices for Japan for the years 1976–2008.

Changes in the real price of land, which rose and fell enormously over our sample period, shifted the share of total house values that were associated with land. Land's shifting shares and structure's constant real price over time meant that our real house price series for Japan was highly, but certainly not perfectly, correlated with real land prices. We multiplied the index of real house prices in Japan by the dollar/yen exchange rate to get the real, U.S. dollar value of Japanese house prices.

Figure 3 shows that the (real, U.S. dollar) price of houses in Hawaii was quite highly correlated with prices of houses in the United States for most of our sample period.[14] That is not too surprising, because both would have

[14]We also estimated specifications that related house prices in Hawaii to house prices in California. California easily accounts for the largest share of visitors to Hawaii from the

been affected by common national factors, like interest rates, inflation, GDP, housing and tax policies and also financial policies (such as those of the GSEs). Notable, however, is the lower correlation between the prices of houses in the United States and in Hawaii from the late 1980s through the middle of the 1990s. The prices of houses in Hawaii appear to have more closely mimicked Japanese house prices then. The price of houses in Hawaii rose sharply during the years of the Japanese bubble economy and then, after the bubble popped, fell significantly in the early 1990s, as did Japanese house prices.

Wealth and Other Indicators of Demand for Houses in Hawaii

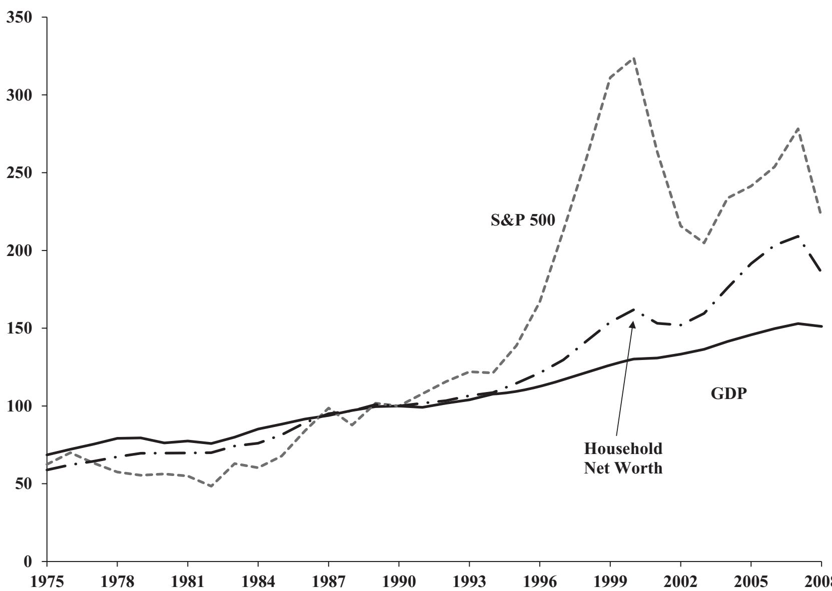
Below we use indicators of demand from the United States and from Japan to help explain house prices in Hawaii. Among the indicators of demands for houses in Hawaii, we use the prices of houses in the United States and in Japan. In addition to reflecting measurable variables, such as incomes and wealth, that affect demand for houses in Hawaii, house prices in the United States and in Japan reflect other, often unmeasurable variables that affect the demand for houses, such as credit conditions, expectations about future economic conditions, and so on. Therefore, we use house prices in the United States and in Japan as one indicator for the United States and for the Japanese demand for houses in Hawaii.

Figures 4 and 5 plot three more-commonly used indicators of demand for houses: stock prices, national net worth and GDP. (Like house prices in Figure 3, each of these series are expressed in real U.S. dollars and are indexed to equal 100 in 1990.) In addition to showing results based on these indicators, we also use an indicator of demand that focuses on higher-income households: the product of national net worth and the share of total wages accruing to households in the top 0.1% of the income distribution.[15] Those with very high incomes may comprise very many of those who bid for and buy houses in Hawaii. In addition and in contrast to national aggregates, this indicator captures the increasing skewness of the income and wealth distributions during our sample period. As such, this indicator would better incorporate the effects of the more-skewed distributions on the maximum bids and thus prices of houses in Hawaii (see Goetzmann, Renneboog and Spaeniers 2009).

United States. The results that were based on California house prices were qualitatively similar to those that were based on U.S. house prices. However, California house prices did not explain house prices in Hawaii as well as U.S. house prices did.

[15]The data for income shares were calculated by Moriguchi and Saez (2008). We downloaded the data from http://elsa.berkeley.edu/∼saez/.

Figure 4 ■ Indicators of U.S. demand for houses in Hawaii.



Note: Indexes of real stock prices (S&P500), real GDP (GDP) and real household net worth (Household Net Worth) for the United States in U.S. dollars. Each index was based to equal 100 in 1990.

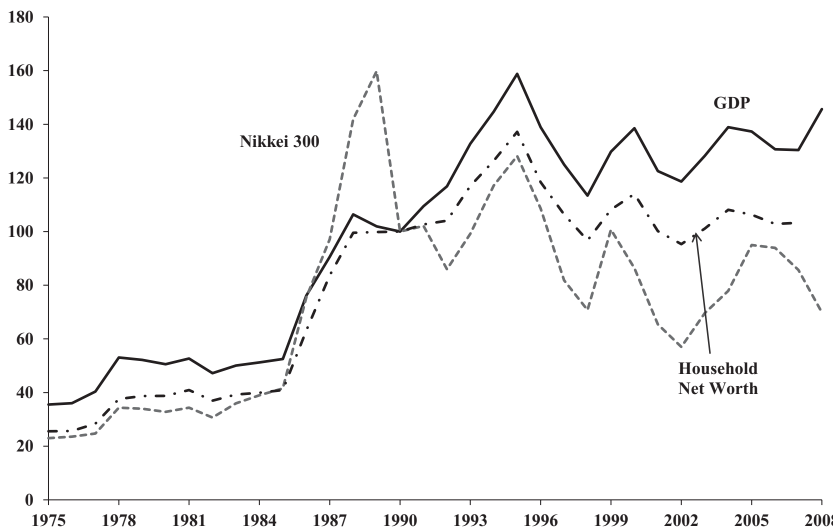
Estimates of the Constant-Coefficient Model

In this section, we show the results of estimating the constant-coefficient, reduced-form model of house prices in Hawaii that we derived in the fourth section. We use the results as a benchmark for the results of estimating models that allow for regime shifts.

Estimated Elasticities

Table 1 shows (OLS) estimates of constant-coefficient (reduced-form) models of the price of houses in Hawaii for 1975–2008. Each column shows the results of regressing the log of the real price of houses in Hawaii on indicators of demands from the United States and Japan, as measured by the logs of real U.S. and Japanese incomes and wealth. Column (1) shows the large and significant estimated elasticities of house prices in Hawaii when we use real house prices in the United States and in Japan as indicators of demand. We estimated the elasticity of house prices in Hawaii to U.S. house prices to be

Figure 5 ■ Indicators of Japanese demand for houses in Hawaii.



Note: Indexes of real stock prices (Nikkei 300), real GDP (GDP) and real household net worth (Household Net Worth) for Japan in U.S. dollars. Each index was based to equal 100 in 1990.

1.27; the estimated elasticity with respect to Japanese house prices was 0.33. Both of these coefficients were statistically significant.[16]

The estimated price elasticities in Table 1 for the other indicators of demand are much smaller. The estimated elasticities with respect to stock prices were a significant 0.22 and an insignificant 0.21, respectively, for the United States and for Japan (column 2). The estimated U.S. and Japanese price elasticities of net worth (column 3) were a significant 0.44 and an insignificant 0.18, respectively. Column 5 shows the estimated elasticities with respect to the indicator of demand by higher-income households, which was constructed as the product of net worth and the share of incomes that accrued to the top 0.1% of the distribution of household incomes. In contrast to the other estimates in Table 1, and perhaps surprisingly, the estimated U.S. elasticity was small and insignificant (and even slightly negative). The estimated Japanese elasticity for the high-income indicator was quite large (0.45), significant, and larger than for any of the other Japanese indicators.

[16]We discuss our criteria for statistical significance in more detail below.

Table 1 ■ Price of houses in Hawaii: Constant-coefficient models.

	1	2	3	4	5
1. Constant	−2.88*	2.43***	1.58**	0.57	4.36***
	(0.74)	(0.29)	(0.37)	(0.73)	(0.11)
U.S. demand factors					
2. House prices	1.27***				
	(0.17)				
3. Stock prices		0.22*			
		(0.07)			
4. Net worth			0.44*		
			(0.13)		
5. GDP				0.60	
				(0.26)	
6. Net worth × High income share					–0.09
					(0.09)
Japan demand factors					
7. house prices	0.33***				
	(0.05)				
8. Stock prices		0.21			
		(0.08)			
9. Net worth			0.18		
			(0.09)		
10. GDP				0.23	
				(0.13)	
11. Net worth × high income share					0.45**
					(0.11)
R^2	0.84	0.59	0.71	0.71	0.76
Sum of squared residuals	0.48	1.19	.86	0.86	0.46
Log likelihood	24.2	8.79	14.4	14.3	21.4
Residual diagnostics					
First-order autocorrelation coefficient	0.70***	0.87***	0.83***	0.80***	0.71**
	(0.13)	(0.11)	(0.11)	(0.11)	(0.17)
p-Value for Phillips–Perron unit root test	0.02	0.02	0.04	0.04	0.05

Notes: All variables are annual and are expressed in logs of real, U.S. dollars. The sample period is 1975–2008. The dependent variable in each column is the log of real house prices in Hawaii. Each regression is estimated by OLS. Standard errors are in parentheses. Asterisks indicate ratios of estimated coefficients to their standard errors: *>3, **>4 and ***>5.

Unit Roots, Statistical Significance and Cointegration

Because the incomes and wealth of these two countries tended to rise over time, we also expected house prices in Hawaii to have risen over time. Trends raise issues that are associated with unit roots and cointegration.

We could not reject the hypothesis of a unit root for any of the data series that we use in the estimated reduced forms for house prices in Table 1. As a consequence, the t-statistics and p-values that are calculated in the standard way do not follow their standard distributions.

Trends in the variables that we use for Table 1 raise concern that they might be spuriously correlated. To allay that concern, we test whether house prices in Hawaii are cointegrated, rather than spuriously correlated, with wealth and other indicators of U.S. and Japanese demand. The p-values for the Phillips–Perron tests for unit roots in the residuals, shown in the bottom row of Table 1, never exceeded 0.05. Those p-values imply that we can reject the hypothesis of no cointegration for each of the five specifications in Table 1.

As statistical tests reject that the three variables in each regression were not cointegrated, we conclude that the reduced-form coefficients were estimated consistently. Relying on those consistent estimates, we then report "significance" that is based on the ratio of the estimated coefficients relative to their standard errors and that makes some allowance for those ratios not following standard t-distributions. Often, regression tables denote statistical significance at the 0.10, 0.05 and 0.01 levels (or better) by attaching 1, 2 or 3 asterisks to the estimated coefficients. Typically, those levels correspond to calculated t-statistics of 1.64, 1.96 or 2.32 (or more in absolute value).

To allow for the nonstandard distributions of the ratios of estimated coefficients to standard errors, we attached an asterisk to each estimated coefficient in each regression table (Tables 1–5) according to the following rule: for ratios that exceeded 3, 4 or 5, respectively, we attached 1, 2 or 3 asterisks. In effect, that means that we attached a number of asterisks that corresponded to ratios that were at least double the usual minimums of 1.64, 1.96 and 2.32. Thus, we use "significant" to refer to coefficients that had ratios of at least four, about double the critical value for a standard t-statistic at a significance level of 0.05.

Despite accepting cointegration, the OLS residuals from the reduced-form estimates in Table 1 were highly autocorrelated. The diagnostic statistics for the residuals, which are shown in the bottom rows of Table 1, show that each of the demand indicators produced a first-order autocorrelation coefficient for the residuals that was at least 0.70. Highly autocorrelated residuals are often a

Table 2 ■ Price of houses in Hawaii: Constant-coefficient models (subperiods).

	1975–2008 1	1975–1985 2	1986–1996 3	1997–2008 4	1987–2000 5	1975–1986, 2001–2008 6
Constant	−2.88*	.52	15.0*	−6.91	7.12	−5.24***
	(0.74)	(2.38)	(4.79)	(2.69)	(4.22)	(0.78)
U.S. demand indicator						
House prices	1.27***	0.69	−3.03	1.94***	−1.25	2.05***
	(0.17)	(0.55)	(1.03)	(0.24)	(0.82)	(0.23)
Japan demand indicator						
House prices	0.33***	0.12	0.75***	0.53	0.70**	0.00
	(0.05)	(0.17)	(0.09)	(0.46)	(0.16)	(0.10)
R^2	0.84	0.27	0.91	0.90	0.79	0.95
Sum of squared residuals	0.48	0.05	0.03	0.08	0.07	0.12
Log likelihood	24.2	14.3	16.2	13.0	17.5	22.8

Notes: All variables are annual and are expressed in logs of real, U.S. dollars. The dependent variable in each column is the log of real house prices in Hawaii. Each regression is estimated by OLS. Standard errors are in parentheses. Asterisks indicate ratios of estimated coefficients to their standard errors: *>3, **>4 and ***>5.

signal of some kind of misspecification, perhaps of functional form, of omitted variables, or of time-varying coefficients.

Time-Varying Coefficients

Our auction-based model of house prices implies that fluctuations over time in the relative wealth of nations can lead to large fluctuations in the effects, or coefficients, of U.S. and Japanese demand on the prices for houses in Hawaii.

Figures 4 and 5 show that there have been large shifts in the incomes and wealth in Japan relative to those in the United States. Japanese (relative) wealth rose sharply after the middle of the 1980s and fell sharply in the 1990s, when the Japanese economy stagnated and the U.S. economy flourished. Figure 3 shows that house prices in Japan relative to those in the United States also rose during the late 1980s and then sagged during the 1990s. Our auction-based model suggests then that the elasticities of house prices in Hawaii with respect to demand from the United States and from Japan might shift considerably, and in opposite directions, over the 1980s and 1990s. After the middle of the 1980s, when Japanese wealth was relatively higher, so too should have been the estimated elasticities of house prices in Hawaii with respect to Japanese demand; then after Japanese fortunes reversed dramatically during the 1990s,

Table 3 ■ Price of houses in Hawaii: Regime-shifting models.

	1	2	3	4	5
U.S. demand factors					
1. Constant	−5.21***	3.09	−8.11*	−16.3**	3.96***
	(0.61)	(2.00)	(2.17)	(3.38)	(0.02)
2. House prices	2.04***				
	(0.13)				
3. Stock prices		0.21			
		(0.49)			
4. Net worth			2.46***		
			(0.42)		
5. GDP				4.23***	
				(0.68)	
6. House price × high income share					0.15***
					(0.03)
7. S.E.E. (σ)	0.08**	0.01	0.08	0.05	0.04**
	(0.02)	(0.15)	(0.04)	(0.02)	(0.01)
Japan demand factors					
8. Constant	0.24	2.76**	2.83***	2.60***	4.17***
	(0.92)	(0.68)	(0.26)	(0.35)	(0.05)
9. House price	0.95**				
	(0.21)				
10. Stock prices		0.39			
		(0.15)			
11. Net worth			0.35***		
			(0.06)		
12. GDP				0.38**	
				(0.08)	
13. House price × high income share					0.46***
					(0.07)
14. S.E.E. (σ)	0.08**	0.23***	0.12***	0.12***	0.16**
	(0.02)	(0.03)	(0.02)	(0.02)	(0.04)
R^2	0.93	0.46	0.87	0.86	0.77
Sum of squared residuals	0.20	1.58	0.39	0.41	0.44
Log likelihood	39.1	23.8	27.2	30.0	28.3
Residual diagnostics					
First-order autocorrelation coefficient	0.41	0.91***	0.59*	0.65**	0.73
	(0.17)	(0.11)	(0.15)	(0.14)	(0.15)
p-Value for Phillips–Perron unit root test	0.01	0.62	0.05	0.08	0.16

Notes: All variables are annual and are expressed in logs of real, U.S. dollars. The sample period is 1975–2008. The dependent variable in each column is the log of real house prices in Hawaii. All regime-shifting regressions are estimated by maximum likelihood. Standard errors are in parentheses. Asterisks indicate ratios of estimated coefficients to their standard errors: *>3, **>4 and ***>5.

Table 4 ■ Davidson–McKinnon specification tests.

Explanatory variable	Estimated coefficient
1. Constant	0.02
	(0.23)
Fitted values	
2. Constant-coefficient model	0.03
	(0.16)
3. Regime-shifting model	0.97***
	(0.15)
R^2	0.93
Sum of squared residuals	0.20
Log likelihood	39.0

Notes: The table contains the result of a regression of the log of real house prices in Hawaii on the fitted values from the constant-coefficient model (column 1 of Table 1) and the regime-shifting model (column 1 of Table 3). Both the constant-coefficient and the regime-shifting model estimates used the logs of real U.S. and Japanese house prices in U.S. dollars as explanatory variables. Standard errors are in parentheses. Asterisks indicate ratios of estimated coefficients to their standard errors: *>3, **>4 and ***>5.

Table 5 ■ Effects of demand from the higher-demand country and from the lower-demand country on the price of houses in Hawaii.

Explanatory variable	Estimated coefficient
1. Constant	0.03
	(0.21)
Sources of demand	
2. Higher-demand country	0.98***
	(0.07)
3. Lower-demand country	0.02
	(0.06)
R^2	0.93
Sum of squared residuals	0.20
Log likelihood	39.0

Notes: The table contains the result of a regression of the log of real house prices in Hawaii on the fitted values from the regime-shifting model (column 1 of Table 3) for the higher-demand country and for the lower-demand country. The demand indicators used as explanatory variables in the regime-shifting model estimates are the logs of real U.S. and Japanese house prices in U.S. dollars. Standard errors are in parentheses. Asterisks indicate ratios of estimated coefficients to their standard errors: *>3, **>4 and ***>5.

so too should have the coefficients of U.S. and of Japanese demand on house prices in Hawaii.

Figure 3 shows that house prices in Hawaii were, indeed, strongly correlated with Japanese demand (for example, as indicated by Japanese house prices) for about a decade beginning in the middle of the 1980s. Other than for that period, however, those two series seem much less correlated. Instead, house prices in Hawaii, both before and after the Japanese decade of dominance, quite clearly were much more correlated with U.S. demand (as indicated by the price of houses in the United States). Thus, house prices in Hawaii tended to be highly correlated with the wealth of a country only when that country was relatively wealthier.

Estimates for Subperiods

To analyze whether the effects on house prices of its demand changed with each country's fortunes, we applied the constant-coefficient specification that we used for column 1 of Table 1 to data for several subperiods. For ease of comparison, we repeat in column 1 of Table 2 the full-sample results in column 1 of Table 1.

To see if the elasticities of house prices in Hawaii with respect to demand did shift importantly over time, we estimated the column 1 specification for each of three subperiods. The results are shown in columns 2–4. Column 2 shows that the elasticity with respect to U.S. demand, though insignificant, was much larger than that for Japan (0.69 vs. 0.12) during 1975–1985, when U.S. incomes and wealth were relatively higher.

In the 1986–1996 subperiod, when Japanese wealth was relatively larger, the estimated coefficient on Japanese demand is large (0.75) and significant, while the estimated U.S. coefficient was insignificant, negative and large. After the middle of the 1990s, the reversal of Japanese fortunes was matched by a reversal of coefficients. Column 4 shows the estimates for the 1997–2008 subperiod. Then, the estimated U.S. demand elasticity soared to 1.94, while the Japanese elasticity declined somewhat and was no longer significant. The negative correlation over time of the estimated U.S. and Japanese elasticities and the negative correlation of the estimated U.S. elasticity with the relative wealth of Japan are what our model predicts.

Shifts in two countries' coefficients that are sufficiently abrupt, large and negatively correlated can be regarded as regime shifts. Table 3 presents the results of estimating specifications that allow for regime shifts. The estimates in column 1 of Table 3 imply that house prices in Hawaii were in a "Japanese regime" from 1987 through 2000. All of the other years in our 1975–2008 sample period were estimated to be in a regime where house prices were determined solely by U.S. demand.

Columns 5 and 6 of Table 2 report the results of estimating a constant-coefficient model separately for the years of the United States regime (1975–1986 plus 2001–2008) and for the years of the Japanese regime (1987–2000). (The regimes are implied by the estimates in column 1 of Table 3. We fully discuss Table 3 below.) Column 5 shows that the estimated coefficient for Japanese demand was large (0.70) and significant, while the United States demand coefficient was negative and insignificant. The coefficient pattern was reversed when fortunes were reversed. During the years when the United States was relatively wealthier, the estimated coefficient on U.S. demand was very large (2.05) and significant, while the estimated Japanese coefficient was virtually zero and insignificant.

A Regime-Shifting Model of the Price of Houses in Hawaii

Our model implies that market shares and thus coefficients vary continuously with relative demand. Throughout, we assume that the country-specific demand coefficients (*i.e.*, the αs above), as opposed to the weights, are constant. Sufficiently large increases of a country's incomes and wealth and thus demand, however, can boost market share, s_t, and thus the weight on that country's demand in determining prices enough that the weight can be approximated as having risen from zero to one. In our context, the regime-shifting model puts a weight of zero on demand from one country at the same time that it puts a weight of one on demand from the other country. As such, regime shifting is an extreme version of time-varying weights.

Next we develop a regime-shifting model, which allows for extreme shifts in the effects on house prices in Hawaii of U.S. and Japanese demands. In Equation (8), the average of house prices at any time t is determined by a share-weighted average of the maximum bids from the United States and from Japan. In contrast, the regime-shifting model requires that prices are determined by the maximum bids from the United States or from Japan, but not both.[17] Thus, the weight on U.S. demand at any time t is either zero or one. When the U.S. weight is zero, the Japanese weight is one, and vice versa. As before, suppose that the expected maximum bid from each country is linear function of the

[17]This basic framework was originally used to estimate supply and demand in markets that can be in "disequilibrium," where the observed quantity is the minimum of the amounts supplied and demanded. See Fair and Jaffee (1972). Our summary of the estimation methodology borrows extensively from Maddala (1986).

wealth of that country and that there is a disturbance term for each country. The average price of houses sold, P_t, in the regime-shifting model then is:

$$P_t = \max\left[\alpha_0^{US} + \alpha_1^{US} W_t^{US} + \varepsilon_t^{US}, \alpha_0^{JP} + \alpha_1^{JP} W_t^{JP} + \varepsilon_t^{JP}\right], \tag{13}$$

where the disturbance terms are distributed as $\varepsilon_t^{US} \sim N(0, v^{US})$ and $\varepsilon_t^{JP} \sim N(0, v^{JP})$.

Denote the probability that the highest bids come from the United States and thus the probability that house prices equal the reservation values of U.S. bidders:

$$\lambda_t = \Pr\left(\varepsilon_t^{US} - \varepsilon_t^{JP} > \alpha_0^{JP} + \alpha_1^{JP} W_t^{JP} - \alpha_0^{US} - \alpha_1^{US} W_t^{US}\right). \tag{14}$$

We denote the maximum bid from each country by B_t. The joint distribution of U.S. and Japanese bids is $g(B_t^{US}, B_t^{JP})$. When the average price is determined by U.S. bids, then the conditional probability of P_t is:

$$h\left(P_t \mid P_t = B_t^{US}\right) = \left(\int_0^{P_t} g\left(B_t^{US}, B_t^{JP}\right) dB_t^{JP}\right) \Big/ \lambda_t. \tag{15}$$

When P_t is determined by Japanese bids, the conditional distribution of P_t is:

$$h\left(P_t \mid P_t = B_t^{JP}\right) = \left(\int_0^{P_t} g\left(B_t^{US}, B_t^{JP}\right) dB_t^{US}\right) \Big/ (1 - \lambda_t). \tag{16}$$

Then the unconditional distribution of P_t is:

$$h(P_t) = \lambda_t h\left(P_t \mid P_t = B_t^{US}\right) + (1 - \lambda_t) h\left(P_t \mid P_t = B_t^{JP}\right). \tag{17}$$

The likelihood function for P_t is:

$$L = \prod_t h(P_t). \tag{18}$$

We can estimate the elasticities of house prices in Hawaii with respect to wealth in the United States and in Japan by maximum likelihood. The method also estimates the probabilities, λ_t, that P_t was determined by U.S. bids and estimates for the United States and for Japan the variance, v, of its disturbance term, ε_t^{US} and ε_t^{JP}. The method allows the data to choose the number of regimes that maximize the likelihood function. A U.S. regime is defined as any year when U.S. rather than Japanese bids determined P_t.

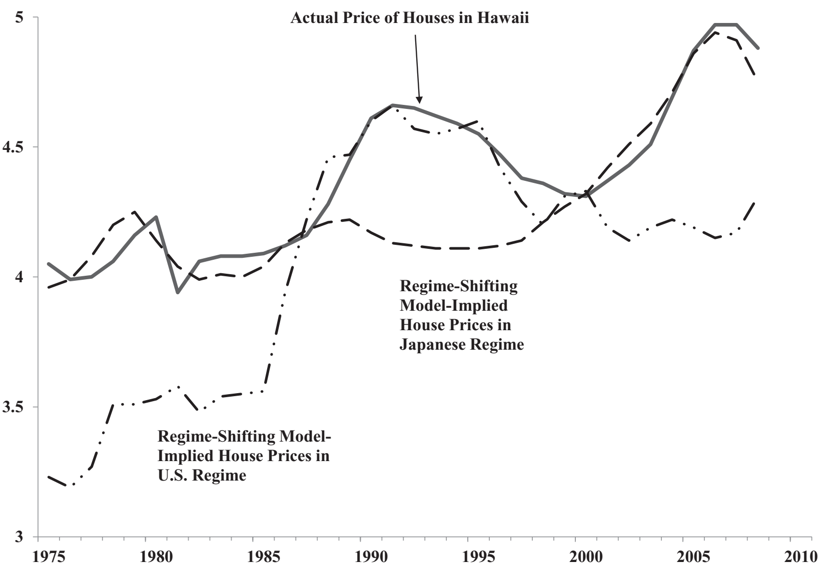
Estimates of the Regime-Shifting Model

Table 3 shows estimates of the regime-shifting model. The estimates in each column use the same indicators of demand as the columns in Tables 1 and 2. The size and significance of the estimated elasticities of the U.S. demand indicators differ greatly in Table 3 from the estimates in Table 1. The regime-shifting coefficients are generally much larger and much more statistically significant. For example, The estimated value of the elasticity of house prices in Hawaii with respect to U.S. net worth rose enormously, from an insignificant 0.60 in Table 1 to become large (2.46) and very significant. Compared with the constant-coefficient results in Table 1, Table 3 also shows that the estimated coefficients in the regime-shifting model for the indicators of Japanese demand have tend to be much larger and much more significant. And, in a sign that allowing for regime shifts may have reduced misspecification, the residuals in Table 3 are generally less autocorrelated than those based on the constant-coefficient specifications. As evidenced by the generally higher R^2s in Table 3, the regime-shifting model generally outperforms the constant-coefficient model.

Figure 6 plots the (log of the real) price of houses in Hawaii and the prices that the estimated coefficients in column 1 of Table 3 and the indicators of U.S. and Japanese demands imply for 1975–2008. Figure 6 shows that estimated U.S. demand clearly exceeded demand from Japan until the mid-1980s. As the 1980s proceeded, the large appreciation of the yen, the onset of the bubble economy in Japan and the tepid performance of the U.S. economy combined to raise Japanese demand above that of the United States. The latter 1980s is the time when contemporaneous accounts noted the surge in Japanese tourism and home purchases in Hawaii. Miller, Sklarz and Ordway (1988) document that the Japanese share of house purchases (including those by Hawaiians) rose dramatically during this period. The Japanese share of houses purchased by offshore buyers then rose even more dramatically. Figure 6 also shows that, even though Japanese demand declined through most of the 1990s, it still exceeded U.S. demand until 1998. Not until estimated U.S. demand rose in the prosperous, latter 1990s was the market for houses in Hawaii estimated to be in a U.S. regime, where it remained through the end of our sample period in 2008.

Figure 7 shows that the estimated probability, λ_t, of being in a U.S. regime remained at nearly 100% into the middle of the 1980s. That probability then plummeted in the latter 1980s to near zero and stayed there through 1997. After that, the continuing stagnation of Japanese incomes and wealth, coupled with the resurgence of U.S. demand, raised the probability of being in a U.S. regime to nearly 100%. Thus, estimates in column 1 of Table 3 of the regime-shifting

Figure 6 ■ Prices of houses in Hawaii: Actual prices and prices implied by the regime-shifting model.



Note: All series are logs of real house prices in Hawaii. The dashed line shows the house prices that are implied by U.S. demand and the estimates in column 1 of Table 3. The dash–dotted line shows the house prices that are implied by Japanese demand and the estimates in column 1 of Table 3.

model suggest that U.S. demand held sway in Hawaii, except for the notable period of about a decade beginning in the latter 1980s.

Additional Evidence Regarding Regime Shifts

The relative numbers of visitors from the United States and Japan to Hawaii by airlines corroborate the boom and bust of Japanese demand for the output, presumably including services of houses, of Hawaii. For the period 1990–2008 when data are available, Figure 8 plots the ratio of the number of visitors from Japan to those from the United States. The ratio was high during the years that the regime-shifting model estimates that house prices were in the Japanese regime. More interesting, perhaps, is that the ratio of Japanese to U.S. visitors continued to grow even as our indicators of Japanese demand were weakening.

Table 4 uses a Davidson–MacKinnon test to directly compare the performance of the constant-coefficient with the regime-shifting model. We regressed house prices in Hawaii on the prices implied by the constant-coefficient model and on the prices implied by the regime-shifting model. The implied prices are the fitted

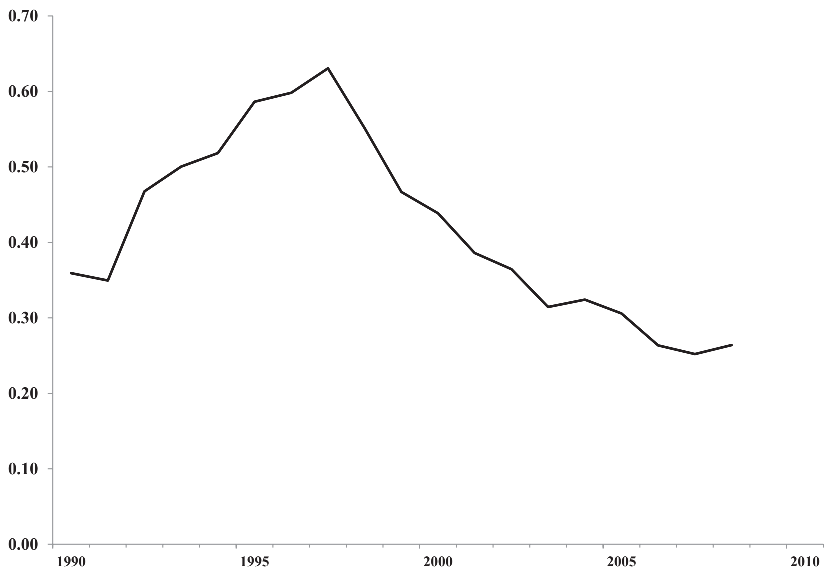
Figure 7 ■ Estimated probability that house prices in Hawaii were in a U.S. regime.

Note: The solid line plots the probability that U.S. demand exceeds Japanese demand and thus that house prices were determined by U.S. demand. The probability is implied by the regime-shifting specification estimates in column 1 of Table 3.

values from the regressions that we report in column 1 of Table 1 and in column 1 of Table 3. The fitted values are constructed as the higher of the implied U.S. and Japanese demands for each year. Table 4 suggests that the regime-shifting model outperformed the constant-coefficient model by a wide margin. The estimated coefficient on the prices implied by the regime-shifting model was strongly significant and nearly one (0.97). In contrast, the estimated coefficient on the prices implied by the constant-coefficient model was not close to being significant and was much smaller (0.33). Thus, the regime-shifting estimates much more closely tracked prices than the constant-coefficient estimates did.

Table 5 provides additional evidence about the performance of the regime-shifting model. In the auction-based model, the demand from the lower-demand country would not be expected to affect prices; only the demand of the higher bidders should affect prices. Table 5 shows the results of our regressing house prices in Hawaii on two variables. The first variable, labeled as demand from the higher-demand country in row 2 of Table 5, again consisted of the fitted values from the regression that we report in column 1 of Table 3. The second variable, labeled as demand from the lower-demand country in row

Figure 8 ■ The ratio of Japanese visitors to U.S. visitors to Hawaii, 1990–2008.



3 of Table 5, was constructed as the lower of the implied U.S. and Japanese demands for year. Row 2 shows that the coefficient on the demand from the higher demand country was 0.98 and was clearly significant. In contrast, demand from the lower demand country had no detectable effect on house prices; its coefficient was near zero (0.02) and insignificant. Thus, the upper envelope of demands strongly affected prices, while the lower envelope did not.

The specifications in Tables 1 and 3 generally passed standard cointegration tests. That suggests that those regression results were not likely to be spurious. Using first-differenced data is another way to allay concerns about spurious regressions. Differencing is typically appropriate for constant-coefficient models. Unfortunately, using first-differenced data is not appropriate for our regime-shifting model, where coefficients shift abruptly. Knowing which country had the larger difference in demand cannot alone tell us which country had the higher level of demand. And, it is the higher level of demand that determines prices. Stated differently, at regime shifts it is not the changes in demand from either country that determines the amounts that prices change, but rather price changes at regime shifts are determined by the difference between the prices implied by the demand from the country whose regime is ending and the prices implied by the demand from the country whose regime is beginning. Thus, when there are regime shifts, first differences of prices will not be consistently related to first differences of the demands from the two countries.

To make some progress in this area, however, we proceeded as follows. First, we first-differenced the data for house prices in Hawaii, in the United States and in Japan. Then, we used the estimates in column 1 of Table 3 to generate the levels of fitted values of house prices in Hawaii. The fitted values include values for the years of regime shifts. We then regressed the first-differences of house prices in Hawaii on three variables: the first differences of U.S. house prices, the first-differences of Japanese house prices and the first-differences of the fitted values that were based on the regime-shift estimates. The estimated coefficients (and standard errors of the coefficients in parentheses below) of that regression are:

$$\begin{array}{l} \Delta P_t = \underset{(0.02)}{0.01} + \underset{(0.67)}{0.179}\Delta P_t^{US} - \underset{(0.16)}{0.146}\Delta P_t^{JP} + \underset{(0.30).}{0.799}\Delta \mathit{FittedValues} \end{array} \qquad (19)$$

Equation (19) shows that the first-differences of house prices in Hawaii were significantly related to the first-differences in the fitted values from the regime-shifting model, but not significantly related to the first differences of house prices in the United States or in Japan. The strong significance of the first-differenced fitted values adds to our confidence that the regime-shift results that were based on the undifferenced data were not spurious. In addition, the results in Equation (13) can be regarded as a first-difference variant of a Davidson–MacKinnon test in that it shows that the regime-shift-based fitted values outperformed the differenced indicators of U.S. and Japanese demand.

Summary and Implications of Regime Shifts

We model house prices as the outcomes of auctions. Prices then reflect the demands of the winning bidders and not the demands of the lower bidders. A sufficiently large increase in the relative incomes or wealth of the group of lower bidders can raise their demands enough that they become the higher-bidding group and, thus, determine house prices. This is a regime shift. While in a regime, prices reflect the demand, and thus the elasticities and volatilities of the measured and of the unmeasured sources of demand, only of the higher-bidding group.

We present evidence that house prices in Hawaii were better accounted for by a regime-shifting model. Both the constant-coefficient and the regime-shifting models provided empirically plausible explanations of house prices in Hawaii. But, by various metrics, the regime-shifting model significantly outperformed the constant-coefficient model.

The estimates of our regime-shifting model imply that prices responded significantly and only to U.S. demand for most years from 1975 through 2008. However, from the middle of the 1980s into the latter 1990s, the regime-shifting estimates imply that the prices of houses Hawaii reflected only Japanese demand.

Shifts from one regime to another imply that the elasticities of the price of houses in Hawaii with respect to U.S. demand and to Japanese demand change dramatically then. Until the end of the regime, the elasticity of prices with respect to demand from the "lower-demand" country is implied to be zero. When it becomes the "higher-demand" country, we are in a new regime and the effects on prices of that country's demand then will have full force. Thus, regime shifting offers one explanation for systematically time-varying coefficients and volatilities.

The views expressed here are not necessarily those of the Federal Reserve System. We thank Stuart Gabriel, Chris Cunningham, seminar participants at the 2008 AREUEA Mid-Year conference, the Federal Reserve Bank of Atlanta, the Federal Reserve Bank of San Francisco, University of Kentucky and University of California Berkeley for helpful comments and suggestions. William Hedberg and Annie Zhang provided excellent research support. All errors are ours alone.

References

Capozza, D. and R. Helsley. 1990. The Stochastic City. *Journal of Urban Economics* 28(2): 187–203.

Fair, R. and D. Jaffee. 1972. Methods of Estimation for Markets in Disequilibrium. *Econometrica* 40: 497–514.

Goetzmann, W., L Renneboog and C. Spaeniers. 2009. Art and Money. Yale School of Management Working Paper.

Hintz, M. 1999. *Hawaii*. Children's Press.

Lindsey, R. 1988. Japanese Riding Hawaii's Real Estate Boom. *The New York Times*. 18 March.

Maddala, G.S. 1986. *Limited-Dependent and Qualitative Variables in Econometrics*. Econometric Society Monograph. Cambridge University Press, Cambridge, UK.

Miller, N.G., M.A. Sklarz and N. Ordway. 1988. Japanese Purchases, Exchange Rates, and Speculation in Residential Real Estate Markets. *Journal of Real Estate Research* 3: 39–49.

Moriguchi, C. and E. Saez. 2008. The Evolution of Income Concentration in Japan, 1886–2005: Evidence from Income Tax Statistics. *Review of Economics and Statistics* 90(4): 713–734.

Parker, J.A. and A. Vissing-Jorgensen. 2010. The Increase in Income Cyclicality of High-Income Households and its Relation to the Rise in Top Income Shares. *Brookings Papers on Economic Activity* 41(2): 1–55.

Peek, J. and J. Wilcox. 1991. The Measurement and Determinants of Single-Family House Prices. *AREUEA Journal* 19(3): 353–382.