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An Early Warning System to Predict the Speculative House Price Bubbles

Christian Dreger and Konstantin A. Kholodilin
DIW Berlin

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Abstract In this paper, the authors construct country-specific chronologies of house price bubbles for 12 OECD countries over the period 1969:Q1–2009:Q4. These chronologies are obtained using a combination of fundamental and filter approaches. The resulting speculative bubble chronology is the one providing the highest concordance between these two techniques. In addition, the authors suggest an early warning system based on three alternative approaches: signaling approach, logit, and probit models. It is shown that the latter two models allow much more accurate predictions of house price bubbles than the signaling approach. The prediction accuracy of the logit and probit models is high enough to make them useful in forecasting the future speculative bubbles in the housing market. Thus, this method can be used by policymakers in their attempts to timely detect house price bubbles and to attenuate their devastating effects on the domestic and world economy.

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Correspondence Christian Dreger and Konstantin A. Kholodilin, DIW Berlin, Mohrenstraße 58, 10117 Berlin, Germany, email: cdreger@diw.de and kkholodilin@diw.de

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The past decade has proved again that the phrase "safe as houses" is a nonsense. Property will always be volatile — and financial crises will always be destructive. The main aim for policymakers must be to sever the connection between the two.

Andrew Palmer,
The Economist, March 5th 2011

1 Introduction

The striking role played by housing markets in the recent financial crisis has demonstrated that shocks in the housing sector can exert huge influence on real economic activity, in particular through their impact on private consumption and residential investment (Goodhart and Hofmann (2008)). Housing loans constitute the largest liability of households and account for a large proportion of bank lending. Especially in the Anglo-Saxon countries, in Spain, and some of the new EU member states, house prices increased tremendously in the pre-crisis period. The bursting of these house price bubbles has triggered massive production losses and raised serious doubts about the sustainability of the growth model in these states. In other countries like Germany, house prices did not accelerate at all. To the extent that the development of house prices is not equal across countries, they may constitute a source for business cycle divergence and can limit the prospects of a common monetary policy in the euro area. Housing markets are therefore highly relevant for the appropriate policy design.

Real house price dynamics depend on institutional features and macroeconomic and demographic conditions, most notably disposable income, the housing stock, inflation, interest rates, bank credit, changes in equity prices, population growth, see Muellbauer and Murphy (2008) and Kholodilin et al. (2010) for recent analyses. Lower interest rates decrease the opportunity cost of capital invested in housing, reduce the servicing cost of mortgage credit and raise the present value of future household earnings. The feedback from property prices to credit growth is stronger in countries with more deregulated mortgage markets, see Tsatsaronis and Zhu (2004). For example, borrowing costs exert a negative effect on real house changes in US regions, see Holly et al. (2010). Although house prices are usually driven by national forces, international components might be relevant in some cases. For instance, the evolution of real house prices in London is linked to New York and other financial centers (Holly et al. (2010)).

In addition, strong monetary growth over the recent years may have supported the emergence of house price bubbles, although the evidence is less clearcut on this point, even if international spillovers are acknowledged (Dreger and Wolters (2009)). A rise in liquidity affects the quantity and marginal utility of money holdings relative to housing and other assets. To restore equilibrium a rebalancing of the liquidity-asset ratio compatible with optimal portfolio allocation is required (Congdon (2005)). The adjustment process triggers higher housing demand and subsequent price increases. According to Adrian and Shin (2008), this effect is amplified through the procyclical balance-sheet management of financial intermediaries. The leverage, i.e., the ratio of total assets to equity is raised during house price booms and reduced in downturns. In addition, the relatively low and stable inflation environment reduced risk premia and might have led to higher financial instability, that is, excess credit pressures and additional leverage (Borio and Lowe (2002)).

Real house prices affect private consumption through a housing wealth and a collateral channel, see Case et al. (2005) and Dreger and Reimers (2009). An increase in housing wealth will raise consumption, due to its impact on expected lifetime income. Consumption expenditures can be shifted upwards without violating budget constraints. However, the effects on housing wealth are not obvious. A permanent increase in house prices could have a positive effect for homeowners, but there is also a negative effect on tenants who have to pay higher rents, and on prospective first-time buyers who have to save more for their intended house purchase, see Poterba (2000) and Goodhart and Hofmann (2008). In addition, increases in the value of owner-occupied housing do not foster the ability of a household to consume more of other goods and services unless that household is willing to realize the increased value, for example, by moving into a less expensive flat. Many households are not expected to do that, including those who intend to leave their homes as bequests. A positive impact of house prices on housing wealth implies that the winners win more than the losers lose. This is more likely to occur if would-be homeowners interpret a house price acceleration as evidence that they may earn future capital gains if they step into the real estate market. Such attitudes may be encouraged by lending institutions in highly competitive and deregulated mortgage markets.

Besides their effect on housing wealth, there is also a collateral effect of house prices, as houses are widely used as a security for loans, see Aoki et al. (2004) and Muellbauer (2008). Collateral effects dramatically improve the response of aggregate demand to house price shocks (Iacoviello (2005)). Households tend to borrow or lend to smooth consumption over time. If liquidity constraints exist, access to credit will be restricted. In periods of rising house prices, however, the value of the collateral the household can offer to banks is higher. Banks become less reluctant to increase their loans. Because of deregulation in mortgage markets, it has become easier and less expensive for consumers to borrow against housing collateral to finance extra consumption (Iacoviello and Neri (2010)). The amplification mechanism due to the increase in borrowing capacity is captured by the financial accelerator, see Bernanke et al. (1999) for the concept. This collateral-based accelerator tends to be higher in more deregulated financial markets, as financial innovation has increased the availability of funds for credit-constrained agents (Goodhart and Hofmann (2008)). Asymmetries are likely, as the effects of shocks to money and credit on house prices seem to be stronger when house prices are booming then otherwise.

Furthermore, housing markets have an impact on the transmission of monetary policy (IMF (2008)). In countries with more flexible mortgage rates and higher loan-to-value ratios, i.e., the ratios between the mortgage amount and the value of the property, the response of private consumption and residential investment to monetary policy shocks is amplified (Calza et al. (2009)). However, the relationship is not unidirectional, as housing wealth also affects money demand, see Dreger and Wolters (2009) and Setzer et al. (2010), among others. There is also evidence that idiosyncratic house price developments have been a major source of divergence in competitiveness and the formation of external imbalances between the euro area member states, because accelerating house prices give rise to a boom in private consumption and import demand (Aizenman and Jinjarak (2009)). House price dynamics influence the performance of the financial system through their impact on the profitability and soundness of financial institutions. Understanding this behavior is of utmost significance for policymakers.

The institutional conditions in housing and mortgage markets are substantially different across euro area member states (ECB (2009)). In the development of real house prices and their spillovers to the real economy, these structural features play a crucial role. For example, Almeida et al. (2006) have reported evidence that the sensitivity of house prices and mortgage borrowings to income shocks is higher in countries with higher loan-to-value ratios. Ludwig and Sløk (2004) and Carroll et al. (2006) have emphasized that the long-run responsiveness of consumption to permanent changes in housing wealth is higher for countries with a market-based than for countries with a bank-based financial system. According to Catte et al. (2004), strong impacts of real house prices on consumption can be detected especially in countries that have large, efficient and responsive mortgage markets. See also Calza et al. (2009). A high degree of mortgage market completeness, i.e., the extent to which the market is able to offer a variety of products and to serve a broad range of potential borrowers is also important. The most crucial element in this regard is the extent to which the markets provide opportunities for housing equity withdrawal, i.e., the magnitude to which the household sector can extract liquidity from the housing market. The response of real house prices to macroeconomic conditions as well as their impact on private consumption and residential investment tends to be larger if a favorable tax treatment of mortgage interest encourages the leveraging of housing equity. Moreover, tax reliefs and subsidies, especially in favor of home ownership, can affect the development in the housing sector, and income tax systems appear to be conducive to house price volatility (van den Noord (2005)).

The importance of housing markets for the real economic performance as well as devastating effects of the housing busts, which bear systemic risks for the whole economy, require reliable tools for timely prediction the housing price bubbles. The aim of this paper is to design an early warning system in order to predict the bursts of the house price bubbles. It uses the the quarterly house price data for 12 OECD countries over the period 1969:Q1-2009:Q4.

The paper is structured as follows. Section 2 describes the method of deriving of a bubble chronology. Section 3, introduces three approaches — signaling approach, logit and probit models — which are used for the prediction of the house price bubbles. Section 4 compares the predictive accuracy of these three alternative approaches. Finally, section 5 concludes.

2 Bubble chronology

Obtaining a bubble chronology is not a trivial task. Because the bubble is not directly observable, it is not easy to distinguish between the growth of the house prices supported by the fundamental factors and that caused by the speculative expectations. We need to separate somehow the two effects in order to extract the speculative component.

In order to do this we propose here the following algorithm. We apply two alternative techniques: one based on estimating the deviations from the fundamental values and another one based on the deviations from the trend regardless of the fundamentals. The use of both techniques can be justified as follows. The speculative bubbles are the periods, when the house prices are higher than their fundamental values, that is, the house prices supported by the fundamentals. However, not each positive deviation from fundamental values can be treated as a speculative bubble, for these deviation might be too short and rather minor. Therefore, this chronology must be compared with that showing the periods, when the prices are above the trend. The final chronology is the one confirmed by both these techniques. Let us consider our algorithm in more details.

First, the real house prices are regressed on a set of the fundamental factors. As fundamental factors the following variables were used: 1) real GDP per capita approximating the disposable income; 2) population size; 3) urbanization, or share of the urban population in the total population; and 4) the own lag of the dependent variable, given the strong time persistence of the house prices (for description of the variables and data sources see Table 1). All these variables should positively affect the house prices. The higher income and population imply that more people need and can afford for the new or existing housing units. The urbanization is expected to have a negative effect on the house prices, since when urbanization is low, it might imply that the more people would migrate from the rural to the urban areas creating an upward pressure on the price of housing. The regression was estimated in levels for each country separately[1]:

$$rhpi_{it} = \alpha_0 + \alpha_1 rhpi_{i,t-1} + \alpha_2 rgdp\_pc_{it} + \alpha_3 pop_{it} + \alpha_4 urbaniz_{it} + \varepsilon_{it} \quad (1)$$

where $rhpi_{it}$ is the logarithm of the real house price in country i in period t; $rgdp\_pc_{it}$ is the real per-capita GDP; pop_{it} is the population; and $urbaniz_{it}$ is

[1] In order to save space we do not report here the estimation results. However, they are available upon request.

the urbanization rate. All other variables, except for urbanization, are also expressed in logs. The fundamental real house price is defined then as:

$$\overline{rhpi_{it}} = \widehat{\alpha_0} + \widehat{\alpha_1} rhpi_{i,t-1} + \widehat{\alpha_2} rgdp\_pc_{it} + \widehat{\alpha_3} pop_{it} + \widehat{\alpha_4} urbaniz_{it} \quad (2)$$

The positive deviations of the actual values from the fundamental values are treated as the potential speculative bubbles. In addition, since these deviations are sometimes too volatile they are smoothed using a spline a regression.

Second, following Mendoza and Terrones (2008) we identified the house price booms (which are not necessarily bubbles) using the Hodrick-Prescott filter applied to the log of the real house prices and different thresholds determining the intensity of the house price growth:

$$cycle_{it} = rhpi_{it} - trend_{it} > \phi \sigma_i^c \quad (3)$$

where $trend_{it}$ is the Hodrick-Prescott trend obtained from the actual real house prices; ϕ is the boom threshold factor, determining the growth intensity, and σ_i^c is the standard deviation of the cyclical component in country i, $cycle_{it}$. Notice that the standard deviations are country specific. When the cyclical component is higher than the predefined threshold, then it is treated as a boom. Various values of the boom threshold factor were tested and was chosen as the one providing the higher concordance between the deviations from fundamental values and booms.

Finally, the fundamental and boom approaches are taken together to produce the speculative bubble chronology. The speculative bubble is thought to occur only when two conditions are met: 1) the smoothed deviation from the fundamental values is positive and higher than 0.5 standard deviation of the deviations and 2) it coincides or partly overlaps with a house price boom. The resulting chronology is shown in Figure 1, which plots the log of the real house prices (bold black lines) against the periods that we identified using the methodology described above as speculative bubbles (gray shaded areas). The precise dates of the speculative bubble periods shown in Figure 1 are presented in Table 3. For example, in the sample period, Australia had undergone through three speculative bubbles: 1988:q1-1989:q2, 2002:q3-2004:q1, and an unfinished bubble that started in 2006:q4. These three periods are displayed as gray areas in Figure 1.

Table 4 reports the number of identified speculative bubbles, their average duration, and the sample. The longest speculative house price bubbles are observed in Japan, UK, and USA: 18, 14.3, and 14 quarters, respectively. The bubbles are the shortest in the Netherlands and Sweden: 5 and 5.5 quarters, correspondingly.

3 Prediction of bubbles

3.1 Signaling approach

The first method used here in order to detect and predict the speculative bubbles is the signaling approach. This method implies that for each relevant indicator of the bubble there exists a certain critical value, violation of which may be considered as an signal of an approaching or ongoing bubble.

We consider the following variables as the relevant ones, that is, as the variables, which might be useful for predicting the speculative bubbles: nominal and real money market rate, money supply, nominal and real money supply growth, spread, real effective exchange rate, rent, house price - to - income ratio, house price - to - rent ratio, investment rate, nominal and real private lending ratio, general government balance - to - GDP ratio as well as growth rate of real per-capita GDP.

The algorithm is as follows. First, each of the above variables is smoothed using the Hodrick-Prescott filter separately for each country. Second, the smoothed series are standardized by dividing them by the country-specific standard deviations. Third, the smoothed and standardized variables are stacked over each other to build a panel. Fourth, a grid of potential critical values, or thresholds, is set comprising the values between 0.2 and 3 with a step equal to 0.2. Thus, 15 possible thresholds are examined. The variable is said to send a signal of bubble when it exceeds a threshold. For each threshold, the accuracy of detecting the bubbles is evaluated by adding up the share of correctly identified bubbles in the total duration of bubbles and the share of correctly identified episodes of no bubbles in the total duration of no-bubble periods. It is clear that both measures move in the opposite directions. The higher the threshold the less bubble periods are identified, however, the less false alarms (signals of bubbles when no bubbles take place) are produced. Therefore, the maximum of this measure is attained when the balance between correctly identifying the bubbles and sending less false alarms is stroken. Formally, this accuracy coefficient can be defined as follows:

$$Z_i^\tau = \frac{A}{A+C} + \frac{D}{B+D} \tag{4}$$

where τ is the threshold ($\tau = 0.2, 0.4, \ldots, 3$); i is the variable index; A, B, C, and D are defined in the following table:

	Bubble	No bubble
Signal	A	B
No signal	C	D

This measure is similar to the signal-to-noise ratio. We decided to add and not to divide the left and right terms, given that at high τ values no false alarms are produced and hence $D = 0$.

From 15 different threshold values, τ, the optimal value is selected such that Z_i^τ is maximized over τ. These optimal values together with the accuracy coefficient,Z_i^τ , are reported in Table 2.

For this optimal threshold an individual signal series is produced for each variable. This signal series is equal to 1, when the smoothed and standardized variable exceeds the threshold, and to 0, elsewhere.

From the individual signal series a composite signal series is computed as a weighted average. The weights are the squared accuracy coefficients, $(Z_i^\tau)^2$. They are squared in order to give even more weight to the variables that are more useful in predicting the speculative bubbles. The composite signal series is depicted in Figure 2 as the continuous black line. The gray shaded areas represent the periods of speculative bubbles.

3.2 Logit/probit approach

Logit/probit approach is an alternative technique of detecting and predicting the speculative bubbles. It allows determining the sign and significance of the influence of each of the relevant variables in predicting the speculative bubbles. In general, these two — logit and probit — techniques can be formulated as:

$$Pr(R_{it} = 1|X_{it}) = F(X_{it}\beta + \varepsilon_{it}) \tag{5}$$

where $Pr(\bullet)$ is the conditional probability of the speculative bubble; is the reference chronology of the speculative bubbles; X_{it} is the set of relevant variables listed in the section on the signaling approach plus the property tax rate; $F(\bullet)$ is some cumulative probability function (logit or Gaussian one);

ε_{it} disturbance term. The difference between the logit and probit models lies in the corresponding probability functions.

Here we apply the logit and probit approaches to the panel data. The fixed effects were accounted for by subtracting from all the variables, except for the dummy ones, their within-group means. Then, the pooled logit and probit estimation was applied to these demeaned data.

The estimation results of both models are reported in Table 5. Only the variables that are statistically significant at least at 10% level were retained. Most of them have positive signs. Three variables have negative signs, namely: 1) square of lending-to-GDP ratio, which reflects a non-linear relationship between this ratio and bubble (when lending ratio increases the speculative bubble is growing too, however, after certain threshold when too much lending takes place, the bubble begins to burst); 2) interaction between the property taxation and general government balance-to-GDP ratio, which means that a combination of high taxation of property and large budget surplus reduce the probability of a speculative bubble; and 3) mortgage market deregulation, which implies that easing of the mortgage market regulations decreases the probability of a speculative bubble. Notice also that some variables —real effective exchange rate, money supply growth, per-capita GDP growth, lending-to-GDP ratio, and house price-to-income ratio growth— are taken with lags, which indicates that they can serve as leading indicators of speculative bubbles.

Figures 3 and 4 compare the model-derived probabilities of speculative bubbles based on the logit and probit models (continuous black line) to the binary reference chronology[2] (gray shaded areas). Both models produce very similar results and allow capturing the bubbles quite accurately. Moreover, the probit and logit as well as signaling method appear to be contemporaneous with the speculative bubble of house prices.

[2]Notice that in some cases (Italy, Japan, and the Netherlands) no speculative bubbles are shown. The reason is that in those cases due to the missing data the estimation sample starts after the last speculative bubble period is over.

4 Evaluating the accuracy of predicting the bubbles

The accuracy of the alternative prediction approaches presented above can be evaluated using the Quadratic Probability Score (QPS) measure, which is defined as follows:

$$QPS = \frac{1}{T}\sum_{t=1}^{T}(R_{it} - P_{it}^{j})^2 \qquad (6)$$

where P_{it}^{j} is the j-th alternative model-derived probabilities of speculative bubbles (based on signaling approach as well as on logit and probit models). QPS varies between 0 and 1. The lower the QPS the more precise are the predictions of the speculative bubbles.

The QPS computed for all three models is reported in Table 6.

It can be seen that the Signaling approach is much less accurate than the logit and probit ones. The latter two produce practically identical results in terms of the predictive power of the speculative bubbles. The forecasting accuracy of the logit and probit models is relatively high. This implies that they can be used as an early warning system in order to predict the future speculative bubbles in the housing markets.

5 Conclusion

In this paper, we constructed the country-specific chronology of the house price bubbles for 12 OECD countries. These chronologies were obtained using a combination of a fundamental and filter approaches. The resulting speculative bubble chronology is the one that provides the highest concordance between these two techniques.

In addition, we suggested an early warning system based on three alternative approaches: signaling approach, logit and probit models. The predictive accuracy of these three approaches was tested against the speculative bubble chronologies we determined in the first step. It was shown that the latter two models allow much more accurate predictions of the house price bubbles than the signaling approach. The prediction accuracy of the logit and probit models is high enough to make them useful in forecasting the future speculative bubbles in housing market.

Thus, our method can be considered as an important tool to be used by the policymakers in their attempts to timely detect the house price bubbles and attenuate their devastating effects on the domestic and world economy.

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Appendix

Table 1: Data description

Variable	Definition	Source
House price index		NiGEM
Money supply		Datastream
Nominal and real GDP		Datastream
Nominal and real investment		Datastream
GDP deflator		Datastream
Long-term interest rate	3-month interest rate	Datastream
Short-term interest rate	10-year interest rate	Datastream
Lending to households		Datastream
Nominal exchange rate		Datastream
Real effective exchange rate		Datastream
Population		Global Insight
Urban population		Global Insight
Rent index		Global Insight
Real house price index	House price index / GDP deflator	own calculation
House price-income index	House price / GDP	OECD
House price-rent index	House price / Rent	OECD
Investment-to-GDP ratio	Nominal investment / Nominal GDP	own calculation
Real per-capita GDP	GDP / Population	own calculation
Urbanization	Urban population / Population	own calculation
Lending rate	Lending / BIP	own calculation
Spread	Long-term – Short-term interest rate	own calculation
General government balance-to-GDP ratio	General government balance / GDP	OECD
Property taxation	Property tax revenues / GDP	OECD
Mortgage market deregulation	Dummy: 1 after deregulation, 0 otherwise	Agnello and Schuknecht (2009)

Table 2: Optimal thresholds for signaling approach

Variable	Optimal threshold	Accuracy coefficient
Money market rate	0.4	1.25
Real effective exchange rate	1.0	1.38
Rent	0.4	1.17
House-price-to-income ratio	1.0	1.44
House-price-to-rent ratio	1.0	1.48
Investment-to-GDP ratio	1.0	1.47
Lending-to-GDP ratio	1.0	1.23
Spread	3.0	1.01
Money supply	0.2	1.12
General government balance to GDP ratio	1.4	1.02
Real money market rate	0.4	1.24
Money supply growth	0.8	1.48
Real money supply growth	1.2	1.4
Nominal lending growth	0.6	1.39
Real lending growth	1.0	1.39
Growth rate of real per-capita GDP	0.2	1.34

Table 3: Chronology of the speculative bubbles of house prices

Beginning of bubble	End of bubble	Beginning of bubble	End of bubble
Australia		Netherlands	
1988q1	1989q2	—	1978q2
2002q3	2004q1	Portugal	
2006q4	—	1998q4	2001q1
Canada		Spain	
1972q3	1974q3	1973q1	1974q2
1980q2	1981q2	1976q3	1978q2
1986q1	1989q4	1986q2	1991q2
2006q1	2007q1	2003q1	2007q1
France		Sweden	
1979q4	1980q4	1993q4	1994q2
2002q4	2006q2	2005q3	2007q2
Germany		Switzerland	
1992q4	1994q3	—	1973q2
Italy		1987q1	1989q3
—	1981q4	UK	
1988q3	1992q1	1971q4	1973q3
Japan		1985q4	1989q1
1986q2	1990q3	2002q2	2007q2
		USA	
		1977q1	1978q4
		2001q2	2006q1

Table 4: Descriptive statistics of the house price speculative bubbles

Country	Number of bubbles	Average duration of bubble, quarters	Estimation sample
Australia	3	8.7	1986q3-2009q4
Canada	4	8.8	1970q2-2009q4
France	2	10.0	1970q2-2009q4
Germany	1	8.0	1991q2-2009q4
Italy	2	9.0	1981q2-2009q4
Japan	1	18.0	1969q4-2009q4
Netherlands	1	5.0	1977q2-2009q4
Spain	4	13.0	1971q2-2009q4
Sweden	2	5.5	1993q2-2009q4
Switzerland	2	12.0	1970q2-2002q3
UK	3	14.3	1971q1-2009q4
USA	2	14.0	1975q2-2009q4

Table 5: Estimation results of panel logit and probit models

Variable	Logit			Probit		
	Coefficient	Std. error	p-value	Coefficient	Std. error	p-value
Constant	-2.343	0.299	0.000	-1.386	0.163	0.000
Real effective exchange rate $t-2$	0.071	0.015	0.000	0.040	0.008	0.000
Investment rate	0.190	0.071	0.008	0.118	0.039	0.003
House price-rent index	0.040	0.008	0.000	0.022	0.004	0.000
Money supply growth	0.202	0.076	0.008	0.112	0.041	0.006
Money supply growth $t-1$	0.234	0.067	0.001	0.138	0.037	0.000
Real GDP per capita growth $t-1$	0.361	0.173	0.038	0.191	0.094	0.043
Lending-to-GDP ratio $t-1$	1.838	0.647	0.005	1.047	0.332	0.002
(Lending-to-GDP ratio)^2	-0.216	0.071	0.003	-0.122	0.037	0.001
Nominal lending growth	0.120	0.067	0.076	0.066	0.035	0.057
House price-to-income ratio growth	0.439	0.073	0.000	0.244	0.037	0.000
House price-to-income ratio growth $t-1$	0.409	0.082	0.000	0.229	0.041	0.000
House price-to-income ratio growth $t-2$	0.298	0.083	0.000	0.157	0.040	0.000
Prop. tax × govt. balance-to-GDP ratio	-0.062	0.017	0.000	-0.033	0.009	0.000
Mortgage market deregulation	-0.665	0.359	0.064	-0.309	0.196	0.115
McFadden R-squared	0.446			0.452		
Akaike info criterion	0.541			0.536		
Schwarz criterion	0.611			0.606		
Hannan-Quinn criterion	0.567			0.563		
LR statistic	438.310			443.346		
Obs with Dep=0	876	Total obs	1061	876	Total obs	1061
Obs with Dep=1	185			185		

Table 6: Prediction accuracy of the alternative models

Model	QPS
Signaling	0.278
Logit	0.074
Probit	0.075

Figure 1: Chronology of the house price bubbles

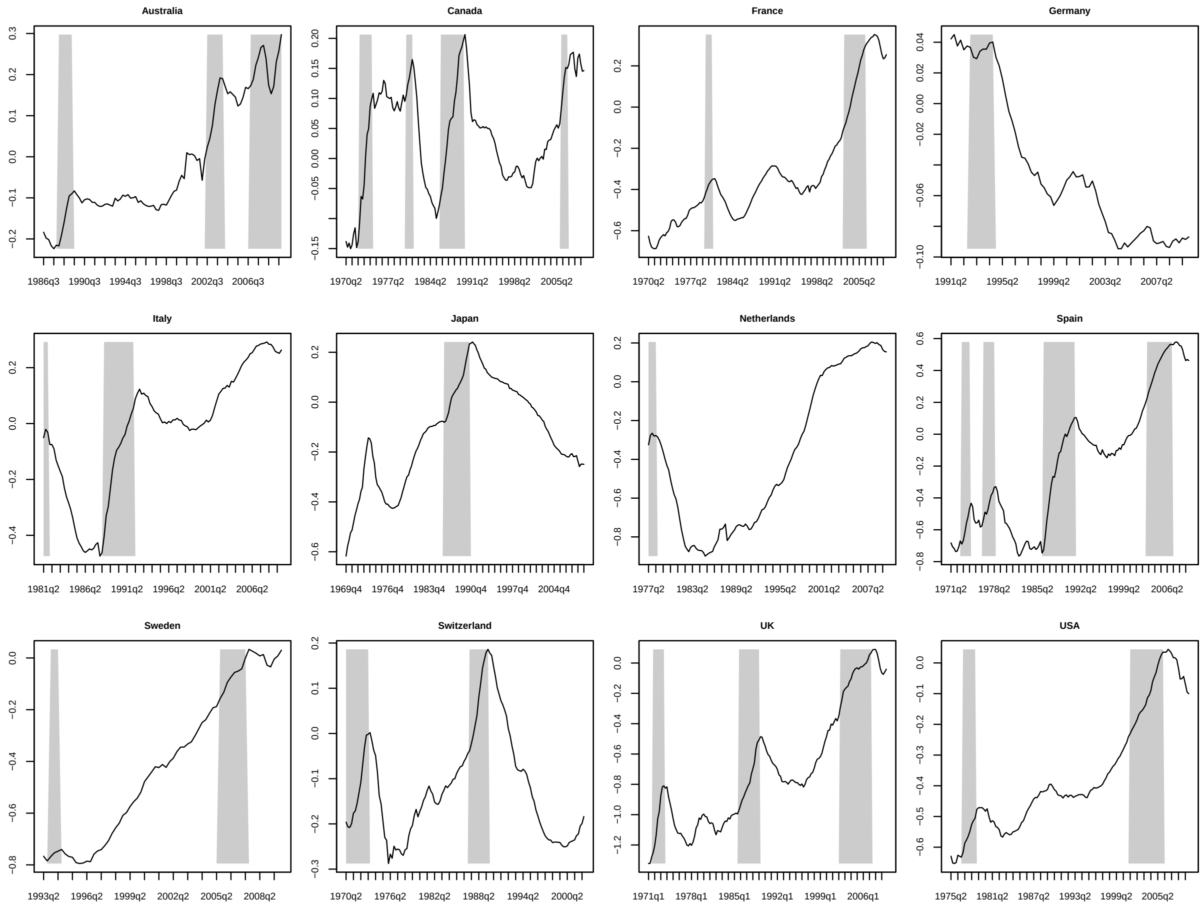

Figure 2: House price bubbles vs. bubble prediction by signaling approach

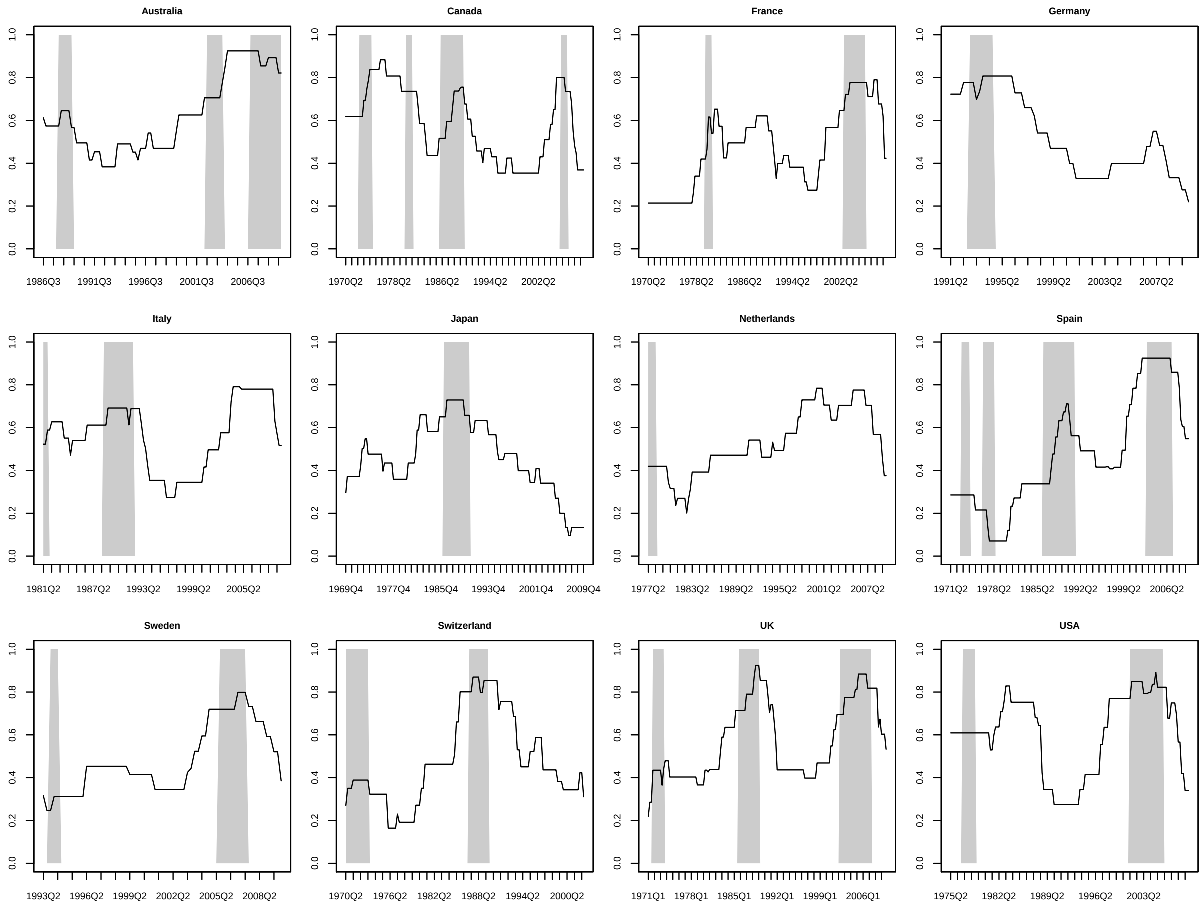

Figure 3: House price bubbles vs. bubble prediction by logit approach

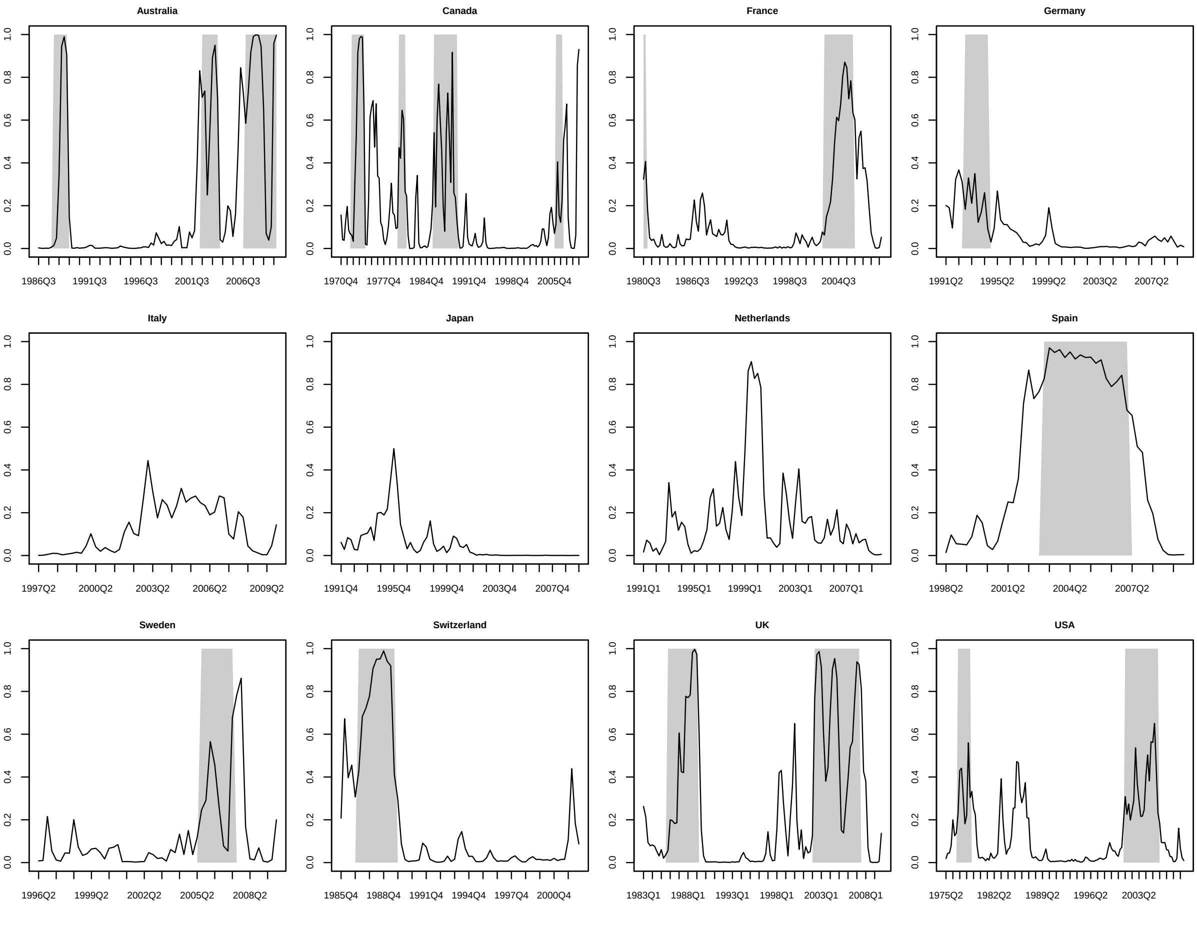

Figure 4: House price bubbles vs. bubble prediction by probit approach