Online Appendix to the paper “Bubbles and crises: The role of house prices and credit”*

André K. Anundsen[a], Karsten Gerdrup[a], Frank Hansen[a], and Kasper Kragh-Sørensen[b]

[a]Norges Bank
[b]Stockholm University

Appendix A: Temporal properties

Table A.1 reports results from both country-specific unit-root tests using an Augmented Dickey-Fuller test (Dickey and Fuller, 1979) for each variable in each country (the fraction of times when the null of I(1) is rejected in favor of the I(0) alternative), as well as the Im-Pesaran-Shin test (see Im et al. (2003)) and a Fisher-type test (see Choi (2001) for a discussion).

---

*This paper should not be reported as representing the views of Norges Bank. The views expressed are those of the authors and do not necessarily reflect those of Norges Bank.

Table A.1: Results from unit root tests

	ADF-test	Im-Pesaran-Shin test	Fisher-type test
	Stationary (#/total)	Stationary (p-value)	Stationary (p-value)
Variable			
Private credit growth (yoy)	0.700	0.000	0.000
Private credit to GDP (yearly change)	0.450	0.000	0.000
Private credit to GDP gap	0.250	0.001	0.040
Household credit growth (yoy)	0.474	0.001	0.000
Household credit to GDP (yearly change)	0.053	0.019	0.000
Household credit to GDP gap	0.105	0.480	0.741
Firm credit growth (yoy)	0.684	0.000	0.000
Firm credit to GDP (yearly change)	0.421	0.000	0.000
Firm credit to GDP gap	0.368	0.000	0.010
House price growth (yoy	0.737	0.000	0.000
House prices to income (yearly change)	0.579	0.000	0.000
House prices to income gap	0.368	0.000	0.026
Non-core funding ratio (yearly change)	0.625	0.000	0.273
Non-core funding gap	0.313	0.018	0.123
Equity ratio	0.125	0.295	0.001
Real GDP growth	0.850	0.000	0.000
Output gap	0.950	0.000	0.000

Notes: The table shows results for the Im-Pesaran-Shin (see Im et al. (2003)) and the Fisher-type (see Choi (2001) panel unit-root tests. The table also reports the results from country-specific Augmented Dickey-Fuller tests (see Dickey and Fuller (1979)). For all tests, we started with an initial lag length of 8, and the optimal lag truncation was decided based on a sequence of t-tests. Only an intercept was included in the ADF-regressions, and – as a cut-off for the country-specific unit root tests – we used critical values from the Dickey-Fuller distribution consistent with a 10% significance level.

Appendix B: Results using the total private sector credit-to-GDP gap

Column (1) in Table B.1 reproduces the results of Column (1) in Table 2 of the paper when the total private sector credit-to-GDP gap is considered instead of separate measures for the household credit-to-GDP gap and the credit-to-GDP gap for non-financial enterprises. The next three columns reproduces Column (2)– Column (4) in Table 2 of the paper, but where again the separate credit-to-GDP gap measures have been substituted by the total private sector credit-to-GDP gap.

Table B.1: Results from baseline models

	(1)	(2)	(3)	(4)
Real credit growth (yoy)	7.194**	7.717***	6.934*	8.452*
	(3.207)	(2.580)	(3.797)	(4.476)
Credit/GDP gap	10.36***	14.17***	15.68***	17.79***
	(1.701)	(2.385)	(2.142)	(2.976)
Global credit/GDP gap		5.652	16.44**	-6.706
		(4.205)	(6.716)	(7.496)
Global HP to inc. gap		17.19***	22.18***	27.28***
		(4.916)	(5.243)	(7.195)
Exuberance HP to inc. (yes/no)			1.026**	2.119***
			(0.405)	(0.349)
Exuberance credit/gdp (yes/no)			1.668***	1.403***
			(0.263)	(0.300)
Non-core funding gap				55.12***
				(11.04)
Equity ratio				-65.05***
				(14.15)
House prices to inc. gap	10.12***	8.366***	10.54***	5.763***
	(2.392)	(2.263)	(3.844)	(1.895)
GDP gap	33.10***	27.53***	57.37***	50.40***
	(9.381)	(9.333)	(12.34)	(16.85)
Country fixed effects	Yes	Yes	Yes	Yes
Pseudo R-Squared	0.228	0.263	0.415	0.463
AUROC	0.824	0.840	0.908	0.923
Countries	20	17	15	13
Crises	32	27	23	20
Observations	2249	2054	1397	990

Notes: The table shows the results from the different specifications reported in the paper, when instead of considering disaggregate credit measures we consider total private sector credot. All models are estimated using a logit model, and the data set cover a panel of 20 OECD countries over the period 1975q1–2014q2. The global variables are constructed using time-varying trade weights. Details on the construction of the global variables and the exuberance measures are provided in Section C and D of this online appendix. Clustered standard errors are reported in parenthesis below the point estimates, and the asterisks' denote significance level; * = 10%, ** = 5% and *** = 1%.

Appendix C: Constructing global variables

Let $\boldsymbol{x}^*_{i,t}$ be a $k \times 1$ vector of country-specific foreign (global) variables for country $i = 1, \ldots N$, i.e. global variables that might affect the probability of a crisis in country i. This vector is defined as a weighted average of the country-specific variables for the countries to which country i is exposed, $\boldsymbol{x}_{j,t}$, $\forall\ j \neq i$. In other words, $\boldsymbol{x}^*_{i,t}$ is a measure of the global variables, as seen from the viewpoint of country i, or the variables in other countries that might affect the probability of a crisis in country i.

Let $\boldsymbol{w}_i$ be a $1 \times N$ weighting vector determining the degree to which area i is influenced by each of the other areas in the sample, where $w_{ii} = 0$ and $\sum_{j=1}^{N} w_{ij} = 1$, with w_{ij} measuring the importance of area j in influencing area i. For a given variable $x^s_{i,t} \in \boldsymbol{x}_{i,t}$, define the vector $\boldsymbol{x}^s_t$ in the following way: $\boldsymbol{x}^s_t = \left(x^{s\prime}_{1,t}, \ldots, x^{s\prime}_{N,t}\right)'$. This vector simply stacks the values of the variable $x^s_{i,t}$ (for example house prices) for all countries. Given this, the foreign variable $x^{*s}_{i,t}$ may be defined in terms of the stacked vector in the following way:

$$x^{*s}_{i,t} = \boldsymbol{x}^s_t \boldsymbol{w}'_i \tag{C.1}$$

i.e. as a weighted average of this variable in all other areas.

We follow Pesaran et al. (2004), Dees et al. (2007a) and Dees et al. (2007b) and use time-varying trade weights based on import and export shares. Thus, the global variables considered in this paper are both country specific and we take account of changes in trade patterns over time. Data on trade flows are taken from the GVAR-database

In Table C.1, we report results when the specifications reported in Column (4) in Table 2 in the paper and Table B.1 in this online appendix are re-estimated using equal weights as an alternative to trade weights.

Table C.1: Equal weights versus trade weights

	(1)	(2)	(3)	(4)
Real credit growth (yoy)	10.19**	8.376**	8.452*	5.471
	(4.467)	(4.184)	(4.476)	(4.074)
Credit/GDP gap			17.79***	17.79***
			(2.976)	(3.316)
Household credit/GDP gap	17.44***	25.65***		
	(4.758)	(5.295)		
NFE credit/GDP gap	14.57***	16.63***		
	(3.694)	(4.359)		
Global credit/GDP gap	-9.293		-6.706	
	(6.959)		(7.496)	
Global HP to inc. gap	23.11***		27.28***	
	(7.611)		(7.195)	
Global credit/GDP gap (equal weights)		9.568		20.04**
		(11.41)		(10.10)
Global HP to inc. gap (equal weights)		11.70		3.502
		(9.042)		(7.082)
Exuberance HP to inc. (yes/no)	2.119***	2.381***	2.119***	2.207***
	(0.368)	(0.329)	(0.349)	(0.297)
Exuberance credit/gdp (yes/no)	1.514***	1.387***	1.403***	0.970***
	(0.306)	(0.313)	(0.300)	(0.270)
Non-core funding gap	56.37***	44.33***	55.12***	42.16***
	(12.13)	(10.51)	(11.04)	(8.051)
Equity ratio	-59.67***	-43.58***	-65.05***	3.195
	(14.49)	(14.88)	(14.15)	(15.81)
House prices to inc. gap	4.198**	2.242	5.763***	3.923*
	(1.862)	(2.231)	(1.895)	(2.160)
GDP gap	45.35***	56.57***	50.40***	79.65***
	(16.50)	(15.83)	(16.85)	(15.67)
Country fixed effects	Yes	Yes	Yes	Yes
Countries	13	14	13	14
Observations	925	977	990	1055

Notes: The models are estimated using a logit specification, and the data set cover a panel of 20 OECD countries over the period 1975q1–2014q2. Clustered standard errors are reported in parenthesis below the point estimates, and the asterisks' denote significance level; * = 10%, ** = 5% and *** = 1%.

Appendix D: Constructing the exuberance indicators

Theoretical background

If we look at housing as any other asset, then the current value of the asset (the house) should be equal to the expected discounted stream of pay-offs. This framework is similar to a standard present value model (see e.g. Gordon and Shapiro (1956) and Blanchard and Watson (1982)), and Clayton (1996) argue that it may equally be considered for housing.

In the housing context, the alternative return to living in a house is the imputed rent, i.e. what it would have cost to rent a house of similar quality. Asset pricing theory therefore suggests that the price of a house at time t is given by:

$$PH_t = \mathbb{E}_t \left(\frac{PH_{t+1} + R_{t+1}}{1+r} \right) \tag{D.1}$$

where $\mathbb{E}_t$ is an expectations operator, PH_t denotes house prices, R_t is the imputed rental price and r is a risk free rate that is used for discounting. This equation simply states that the price of a house today is equal to the discounted sum of the price of that house tomorrow and the value of living in the house for one period (as measured by the alternative cost, i.e. the imputed rent). Equation (D.1) may easily be solved by forward recursive substitution j times to yield:

$$PH_t = \mathbb{E}_t \left[\sum_{i=1}^{j} \left(\frac{1}{1+r} \right)^i R_{t+i} + \left(\frac{1}{1+r} \right)^j PH_{t+j} \right] \tag{D.2}$$

The transversality condition (TVC) that rules out explosive behavior is given by:

$$\lim_{j \to \infty} \left(\frac{1}{1+r} \right)^j PH_{t+j} < \infty \tag{D.3}$$

Imposing the TVC, the unique solution to the difference equation in (D.2) is given as:

$$PH_t = \mathbb{E}_t \left[\sum_{i=1}^{\infty} \left(\frac{1}{1+r} \right)^i R_{t+i} \right] \tag{D.4}$$

showing that the value of a house today, PH_t is equal to the expected discounted value of all future rents, i.e. the pay-off stream in the infinite future. The expression in (D.4) may be thought of as a fundamental house price according to asset pricing theory. It is important to notice that imposing the TVC rules out explosivity, and thus ensures a unique solution to the difference equation.

If we relax the TVC, it can be shown that the (non-unique) solution to the difference equation in (D.2) (see Sargent (1987) and LeRoy (2004)) is given by:

$$PH_t = \mathbb{E}_t \left[\sum_{i=1}^{\infty} \left(\frac{1}{1+r} \right)^i R_{t+i} \right] + B_t \tag{D.5}$$

where B_t is an explosive bubble component. Campbell and Shiller (1987) have shown that (D.5) may alternatively be expressed as:

$$PH_t - \frac{1}{r} R_t = \frac{1+r}{r} \mathbb{E}_t \left[\sum_{i=1}^{\infty} \left(\frac{1}{1+r} \right)^i \Delta R_{t+i} \right] + B_t \tag{D.6}$$

If the fundamentals (the rents), R_t, is a RW process with a drift μ, then:

$$\Delta R_t = \mu + \varepsilon_t, \ \varepsilon_t \sim IIN(0, \sigma^2) \tag{D.7}$$

Conditional on this, we see that $\mathbb{E}_t \Delta R_t = \mu$, and hence that (D.6) may be written as:

$$PH_t - \frac{1}{r} R_t = \frac{1+r}{r} \left[\sum_{i=1}^{\infty} \left(\frac{1}{1+r} \right)^i \mu \right] + B_t \tag{D.8}$$

Solving the infinite geometric sequence above, we find:

$$PH_t - \frac{1}{r} R_t = \frac{1+r}{r^2} \mu + B_t \tag{D.9}$$

Thus, in the absence of explosivity, i.e. when the TVC holds ($B_t = 0$), the asset pricing model implies that house prices should also have a unit root, and that house prices and rents are cointegrated.[1] However, conditional on the assumption that $R_t \sim RW$, any explosive behavior in PH_t suggests that $B_t \neq 0$, i.e. that there is an explosive bubble component that affects house prices (TVC is violated).

With reference to (D.8), it is clear that the bubble hypothesis is rejected as long as house prices are integrated of the first order, I(1). However, if house prices has an explosive root, the asset pricing theory would suggest that there is a bubble (violation of TVC). In the next section, we discuss how we operationalize this model using novel econometric methods.

An econometric operationalization

We have followed Pavlidis et al. (2014) and applied the recursive ADF-based framework suggested by Phillips et al. (2011),Phillips et al. (2015b) and Phillips et al. (2015a) to explore whether there are signs that house prices in a given country moves from following

---

[1] With time-varying risk-free rates, house prices, rents and the risk-free rate should be cointegrated. That said, it seems relatively uncontroversial to assume that the risk-free rate follows an I(0)-process, which implies that it will not help for cointegration.

an I(1) process (TVC satisfied and no bubble) to having an explosive root (violation of TVC and thus bubble). A structural break that moves the process from I(1) to explosivity would suggest that there has been a bubble. Though the theory is not directly applicable to the credit market, we have used the same methods to test for explosive behavior also in credit variables.

Consider the following standard ADF-regression model for country i:

$$\Delta X_{i,t} = \mu_i + \rho X_{i,t-1} + \sum_{j=1}^{p} \Delta X_{i,t-j} + \varepsilon_{i,t} \tag{D.10}$$

When $\rho = 0$, we say that $X_t \sim I(1)$, i.e. that it has one unit root. The standard ADF-test, tests the null of a unit root against the alternative of stationarity ($\rho < 0$). With reference to the asset pricing model, the alternative of stationarity seems less relevant, however. The hypothesis we are interested in testing is whether house prices are I(1) v.s. the alternative that they are explosive, i.e. $\rho > 0$. This approach does however have low power to detect the alternative of explosivity when such episodes are followed by large drops.

The framework suggested by Phillips and co-authors is to consider a recursive version of the ADF test, so that we can explore whether there are periods when a time series exercises I(1) behavior, while there are other periods where it has an explosive root. The general ADF regression that this test is based on takes the following form:

$$\Delta X_{i,t} = \mu_{i,r_1,r_2} + \rho_{i,r_1,r_2} X_{i,t-1} + \sum_{j=1}^{p} \gamma_{i,r_1,r_2} \Delta X_{i,t-j} + \varepsilon_{i,t},\ \varepsilon_{i,t} \sim IIN(0, \sigma^2_{i,r_1,r_2}) \tag{D.11}$$

where $r_1 = \frac{T_1}{T}$ and $r_2 = \frac{T_2}{T}$, with T_1, T_2 and T denoting the sample starting point, end point and the total number of observations. Thus, with reference to the standard ADF regression, we would have $T_1 = 0$ and $T_2 = T$. What we are interested in testing is the hypothesis that $\rho_{i,r_1,r_2} = 0 \Rightarrow X_{i,t} \sim I(1)$ against the alternative that $\rho_{i,r_1,r_2} > 0 \Rightarrow X_{i,t}$is explosive. The relevant test statistic is the ordinary ADF statistic, i.e. $ADF_{r_1}^{r_2} = \frac{\hat{\rho}_{i,r_1,r_2}}{se(\hat{\rho}_{i,r_1,r_2})}$

Phillips et al. (2011) suggested setting $T_1 = 0$, while varying T_2 from $\tilde{T}$ to T, i.e. an expanding forward recursive strategy. To test whether there are any periods with evidence of explosive behavior, they suggested using the sup ADF statistic (SADF), which is given by:

$$SADF(r_1 = 0) = \underset{r_2 \in [\tilde{r}, 1]}{sup}\ ADF_{r_1=0}^{r_2} \tag{D.12}$$

with $\tilde{r} = \frac{\tilde{T}}{T}$. Like the ordinary ADF statistic, the SADF statistic has a non-standard limiting distribution that is skewed to the left. Moreover, the distribution depends on both r_2 and the nuisance parameters. These critical values may, however, be simulated and the null of non-stationarity is rejected in favor of explosivity when the SADF statistic is greater than the corresponding critical value from the right-tail distribution.

While this test has been shown to perform well in the case of only one bubble, it has been shown to function poorly when there are multiple bubbles (see Homm and Breitung (2012)). Therefore, Phillips et al. (2015b) and Phillips et al. (2015a) suggest a modified version of the test, where both T_1 and T_2 are allowed to vary, i.e, both the sample starting point and the sample end point varies. The relevant test statistic is called the generalized SADF (GSADF) statistic and is given by:

$$GSADF = \underset{r_2 \in [\tilde{r},1], r_1 \in [0, r_2 - \tilde{r}]}{sup} ADF_{r_1}^{r_2} \tag{D.13}$$

As with the standard ADF statistic and the SADF statistic, the GSADF statistic has a non-standard limiting distribution, and the distribution of GSADF under the null of non-stationarity depends on both r_1, r_2 and the inclusion of nuisance parameters.[2] A rejection of the null hypothesis indicates that there are signs of explosive behavior.

In most cases it is relevant to ask for what period(s) – if any – the series $X_{i,t}$ exercises explosive behavior. Consider the case where we keep the sample end point fixed, i.e. $r_2 = \bar{r}_2$, and consider the backward ADF (BADF) statistic (Phillips et al. (2015b)):

$$BADF(r_2 = \bar{r}_2) = \underset{r_1 \in [0, \bar{r}_2 - \tilde{r}]}{sup} ADF_{r_1}^{r_2 = \bar{r}_2} \tag{D.14}$$

By (forward) recursively changing $\bar{r}_2$, we then obtain a time series for the BADF statistic. Comparing this to the relevant critical values, $CV_{r_1}^{r_2}$, we can determine for what periods there is evidence of explosive behavior. In our analysis, we have constructed a variable $Exuberance(X_{i,t})$, which is given as:

$$Exuberance(X_{i,t}) = BADF(r_2 = \bar{r}_2) - CV_{r_1}^{r_2} \tag{D.15}$$

which measures the degree of explosive behavior in the variable under consideration at different points in time. When $Exuberance(X_{i,t}) \geq 0$, there is evidence of explosivity in $X_{i,t}$, while there is no evidence of explosivity if $Exuberance(X_{i,t}) < 0$. Thus, we are interested in testing the hypothesis that an increase in $Exuberance(X_{i,t})$ increases the probability of a crisis.

Constructed indicators

Figure D.1 and D.2 plots the implied exuberance measures for all the countries included in our data set.

---

[2] We use the Matlab program accompanying Phillips et al. (2015a) to simulate consistent finite sample critical values.

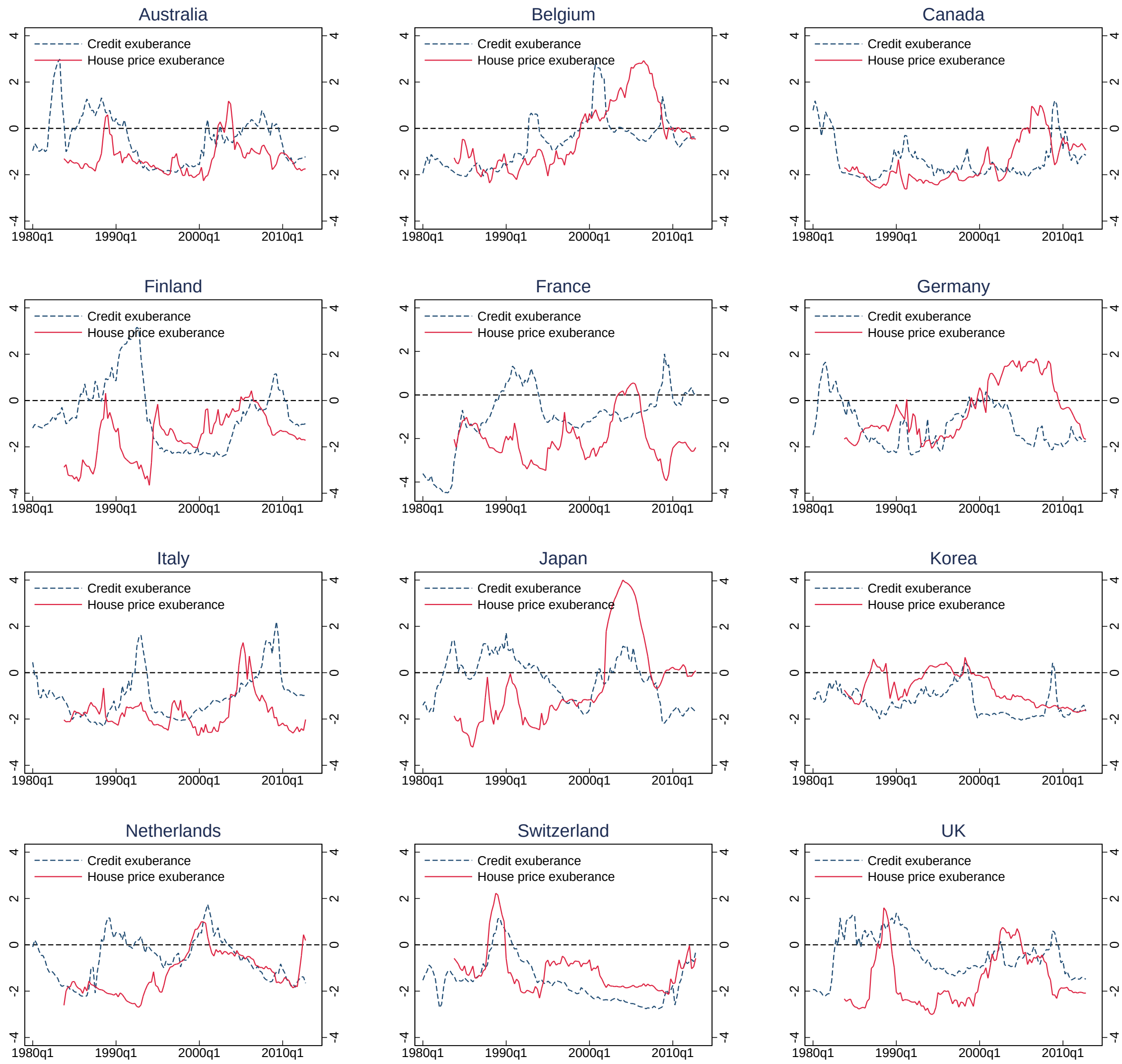


Figure D.1: *Indicator for exuberance in house prices to income and credit to GDP. The figure shows the test statistic less the critical value based on a 5% significance level for house prices to income and private credit to GDP. A positive difference indicates exuberant behavior.*

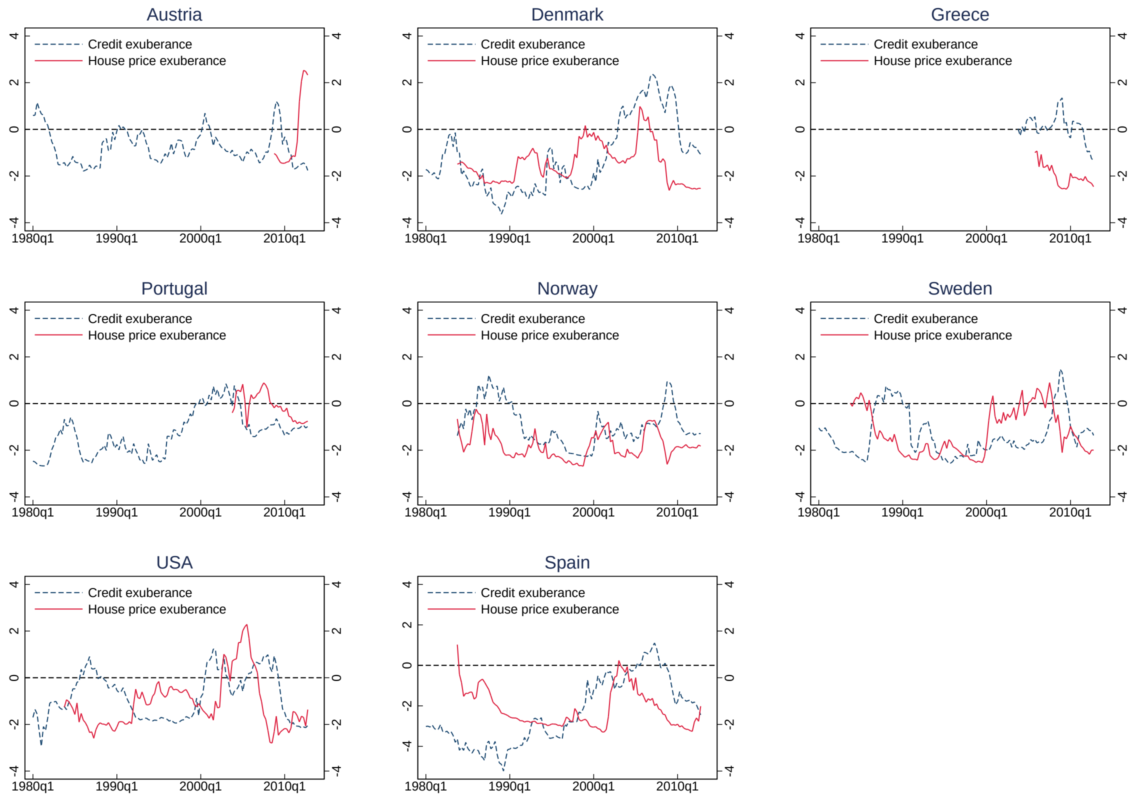


Figure D.2: *Indicator for exuberance in house prices to income and credit to GDP, cont'd. The figure shows the test statistic less the critical value based on a 5% significance level for house prices to income and private credit to GDP. A positive difference indicates exuberant behavior.*

Appendix E: Alternative transformations

Table E.1 and Table E.2 reproduces the results in Table 2 in the paper in the case where we use alternative operationalizations of the variables of interest.

Table E.1: Results when using 4-quarter changes instead of gaps

	(1)	(2)	(3)	(4)
Household credit to GDP (yd)	19.43***	11.79***	4.270	8.892*
	(3.931)	(3.960)	(4.474)	(4.557)
NFE credit to GDP (yd)	18.30***	21.03***	15.35***	10.22**
	(3.505)	(3.820)	(3.156)	(4.764)
Global credit-to-GDP (yd)		2.727	3.146	-9.833
		(5.433)	(5.724)	(8.574)
Global house prices-to-income (yd)		15.48***	11.52	8.000
		(6.000)	(7.184)	(8.369)
Exuberance HP to inc. (yes/no)			1.782***	2.699***
			(0.271)	(0.313)
Exuberance credit/gdp (yes/no)			1.899***	2.298***
			(0.297)	(0.293)
GDP gap	44.00***	38.08***	43.69***	41.97***
	(6.862)	(6.694)	(9.322)	(12.83)
House prices to income (yd)	6.609***	5.397***	6.411***	2.464
	(2.181)	(2.000)	(1.719)	(2.750)
Non-core funding(yd)				40.51***
				(7.475)
Equity ratio				-54.55***
				(12.78)
Country fixed effects	Yes	Yes	Yes	Yes
Pseudo R-Squared	0.210	0.213	0.309	0.350
AUROC	0.817	0.817	0.868	0.884
Countries	20	17	15	13
Crises	29	25	22	19
Observations	1913	1778	1324	897

Notes: The table shows results when we use substitute gap measures in Table 2 in the paper with the 4-quarter changes. Absolute standard errors are reported in parenthesis below the point estimates. The asterisks' denote significance level; * = 10%, ** = 5% and *** = 1%.

Table E.2: Results when using 4-quarter growth rates instead of gaps

	(1)	(2)	(3)	(4)
Real household credit growth(yoy)	3.428**	1.640	5.365*	12.96***
	(1.740)	(2.304)	(3.140)	(3.116)
Real firm credit growth(yoy)	15.48***	17.03***	14.17***	10.46***
	(2.559)	(2.402)	(2.404)	(3.549)
Global real credit growth(yoy)		3.611	11.83*	15.15
		(6.090)	(6.998)	(11.95)
Global real house price growth (yoy)		12.09**	1.929	-2.719
		(5.646)	(6.686)	(7.231)
Exuberance HP to inc. (yes/no)			2.163***	3.042***
			(0.228)	(0.343)
Exuberance credit/gdp (yes/no)			1.649***	1.878***
			(0.303)	(0.291)
Non-core funding(yd)				47.63***
				(8.140)
Equity ratio				-62.40***
				(12.12)
Real house price growth (yoy)	8.487***	7.349***	1.158	-1.257
	(1.719)	(1.734)	(1.796)	(2.430)
Real GDP growth(yoy)	4.814	0.256	9.373*	11.69*
	(4.968)	(4.721)	(5.059)	(6.582)
Country fixed effects	Yes	Yes	Yes	Yes
Pseudo R-Squared	0.188	0.214	0.308	0.377
AUROC	0.801	0.815	0.869	0.897
Countries	20	17	15	13
Crises	29	25	22	19
Observations	1941	1778	1324	897

Notes: The table shows results when we use substitute gap measures in Table 2 in the paper with 4-quarter growth rates. Absolute standard errors are reported in parenthesis below the point estimates. The asterisks' denote significance level; * = 10%, ** = 5% and *** = 1%.

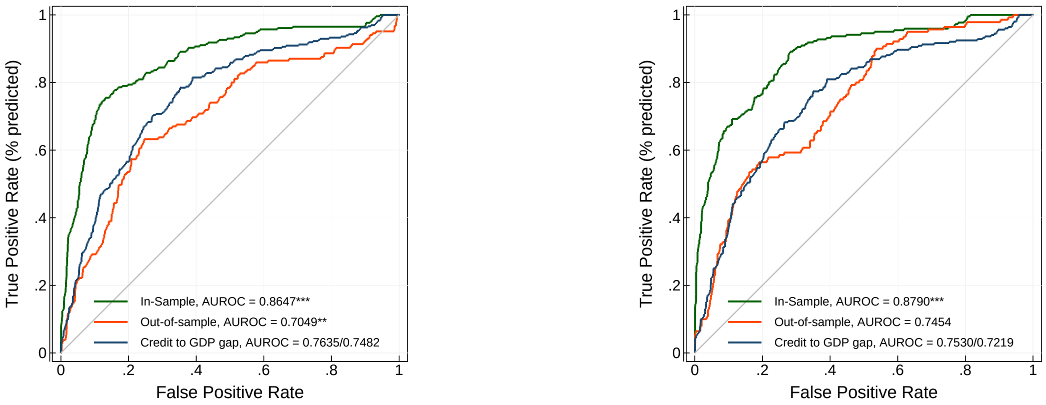
Appendix F: Leave-one-out cross-validation and temporal stability

Out-of-sample performance

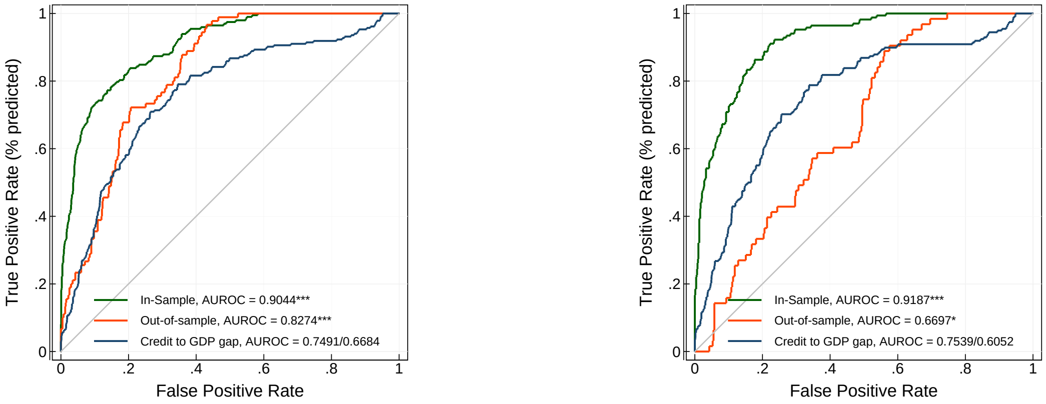
In the paper, we considered an out-of-sample exercise where quasi real-time forecasts for the period 2000–2012 where constructed using data up to 1999 as an estimation sample. Here, we consider a leave-one out cross validation approach. More precisely, we predict the probability of a crisis for every country when the country under consideration is excluded from the estimation. While this approach is uninformative regarding the real-time performance of the models, it will nevertheless shed light on the importance of a country's own history of financial crises in predicting the probability of a crisis in that country. This is because country-specific dummies reflect the number of crises each country has experienced, see also the discussion in Drehmann and Juselius (2014).

As in the paper, we evaluate the out-of-sample properties of each of the models presented in Section 4. All models are evaluated relative to the credit-to-GDP gap as a stand-alone indicator. The out-of-sample performance of the different models is evaluated using ROC and AUROC (confer Section 2 in the paper).

The results from the rolling sample exercise are presented in Figure F.1. There is indeed considerable information in a country's own history of financial crises, as indicated by the marked drop in the AUROC from the in-sample to the out-of-sample predictions. This is consistent with the findings in Drehmann and Juselius (2014). That said, the models are still highly informative (as indicated AUROCs close to 0.8), and do not perform worse than the credit-to-GDP gap.



(a) Model 1 (b) Model 2



(c) Model 3 (d) Model 4

Figure F.1: *In and out-of-sample AUROC/ROC of the models presented in Section 2 of the paper relative to credit-to-GDP gap based on rolling samples. An asterisk indicates that the AUROC is significantly different from that of the credit to GDP gap using a 5% significance level.*

Temporal and cross-sectional stability

Temporal stability

In order to shed light on the *temporal stability* of our models, we have estimated the specifications reported in Column (1)–Column (3) on two different subsamples: a *pre-2000* sample, which uses information only up to 2000 and a *post-1994* sample, which includes information from 1994 onwards. The results are presented in Table F.1.

Independent of the sample period, the marginal effect of the domestic household credit-to-GDP gap is positive and significant in all specifications. The effect of the credit-to-GDP gap for non-financial enterprises is less robust on the post-1994 sample. This suggest that the difference in results in this paper and in Büyükkarabacak and Valev (2010), who consider a post-1990 sample, may at least partly be ascribed to the different sample periods considered. The marginal effect of the house price-to-income gap is also less stable across samples and specifications. Interestingly, the indicator for exuberance in house prices is positive and significant in both cases, suggesting that extreme imbalances in the housing market are an important predictor of financial crises. The exuberance measure for credit is only significant in the pre-2000 sample. The importance of global house prices has strengthened over time, i.e. they seem to have only played a role in the post-1994 period.

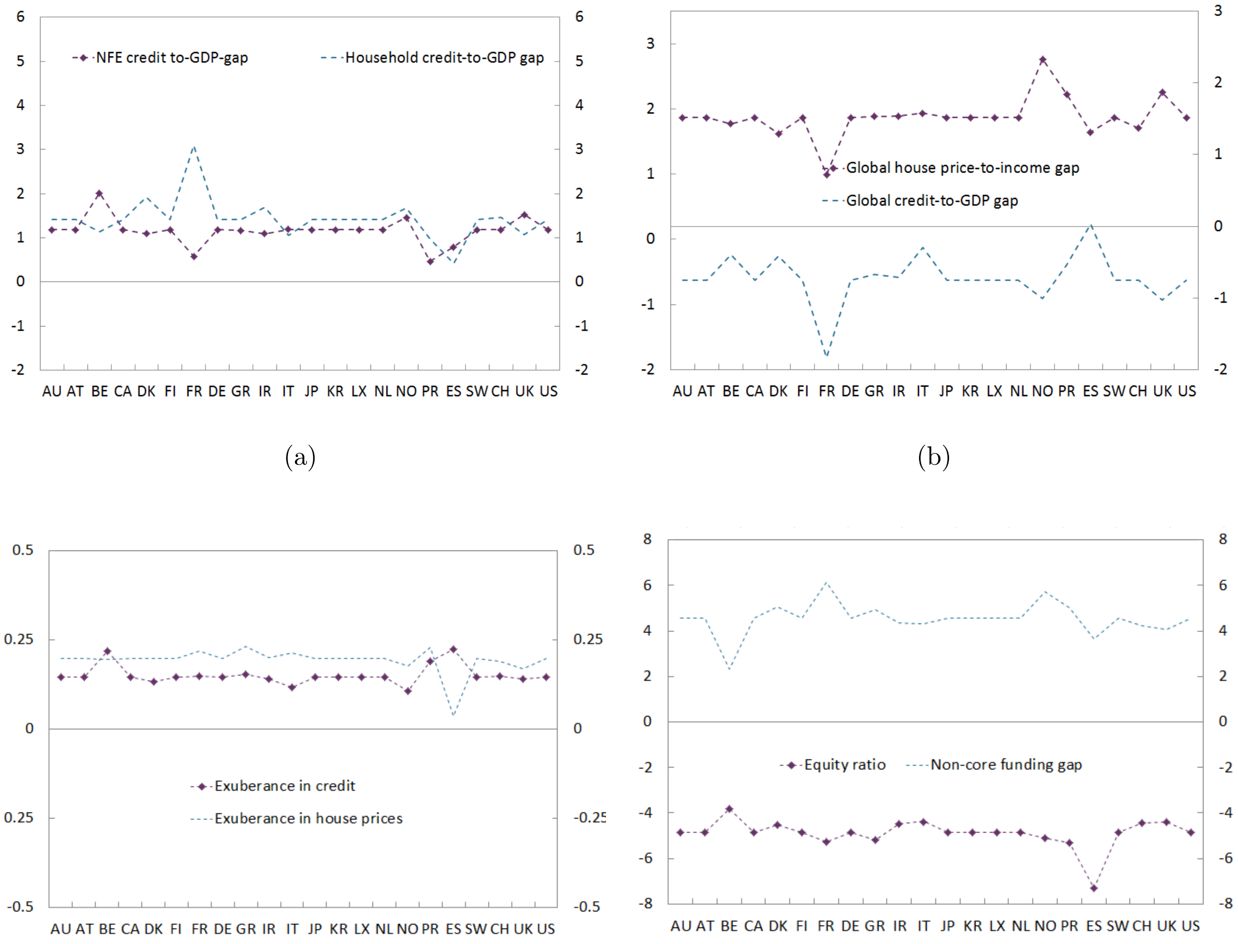
Table F.1: Marginal effects for different samples.

	Model 1		Model 2		Model 3	
	Pre-2000	*Post-1994*	*Pre-2000*	*Post-1994*	*Pre-2000*	*Post-1994*
Real credit growth (yoy)	-0.739*** (0.276)	1.334** (0.633)	-0.814*** (0.273)	2.401*** (0.434)	-0.526 (0.518)	2.388*** (0.504)
Household credit/GDP gap	2.355*** (0.505)	4.964*** (0.631)	2.713*** (0.404)	2.291*** (0.643)	4.043*** (1.006)	2.529*** (0.713)
NFE credit/GDP gap	4.015*** (0.476)	-0.0747 (0.343)	4.177*** (0.412)	0.554 (0.483)	3.670*** (0.524)	0.581 (0.423)
Global credit/GDP gap			0.532 (0.333)	-0.346 (1.019)	0.907 (0.993)	1.896 (1.389)
Global HP to inc. gap			-0.217 (0.367)	6.280*** (0.453)	-1.359 (0.850)	5.842*** (0.409)
Exuberance HP to inc. (yes/no)					0.384*** (0.0737)	0.0988*** (0.0201)
Exuberance credit/gdp (yes/no)					0.224*** (0.0581)	-0.0336 (0.0270)
House prices to inc. gap	0.391 (0.264)	0.412 (0.455)	0.245 (0.255)	0.287** (0.136)	0.357 (0.394)	0.280 (0.171)
GDP gap	1.478*** (0.456)	10.12*** (2.067)	1.309*** (0.489)	7.916*** (0.946)	1.147 (0.875)	7.751*** (0.862)
Countries	14	16	13	13	11	12
Crises	13	19	12	15	10	14
Observations	1035	891	1019	744	540	710

Notes: The table shows the marginal effects from the models excluding banking sector variables in Table 2 in the paper estimated on two different subsamples. The *pre-2000* sample includes information only up to 2000 (i.e. we exclude the global financial crisis of 2007/08), while the *post-1994* sample includes information from 1994 onwards. Absolute standard errors are reported in parenthesis below the point estimates, and the asterisks denote significance level; * = 10%, ** = 5% and *** = 1%.

Cross-sectional stability

We have analyzed the cross-sectional sensitivity of our results by re-estimating the specification reported in Column (4) of Table 2 in the paper, excluding each country in turn. Panel (a)–(d) plots the marginal effects of the different explanatory variables.



(a)

(b)

(c)

(d)

Figure F.2: *Cross-sectional stability of marginal effects based on specifications reported Table 2 in the paper.*

References

Blanchard O, Watson M. 1982. *Crisis in the Economics Financial Structure*. Lexington Books, Lexington.

Büyükkarabacak B, Valev NT. 2010. The role of household and business credit in banking crises. *Journal of Banking & Finance* **34**: 1247 – 1256.

Campbell JY, Shiller RJ. 1987. Cointegration and tests of present value models. *Journal of Political Economy* **95**: 1062–88.

Choi I. 2001. Unit root tests for panel data. *Journal of International Money and Finance* **20**: 249–272.

Clayton J. 1996. Rational expectations, market fundamentals and housing price volatility. *Real Estate Economics* **24**: 441–470.

Dees S, di Mauro F, Pesaran MH, Smith LV. 2007a. Exploring the international linkages of the Euro area: A global VAR analysis. *Journal of Applied Econometrics* **22**: 1–38.

Dees S, Holly S, Pesaran MH, Smith LV. 2007b. Long run macroeconomic relations in the global economy. *The Open-Access, Open-Assessment E-Journal* **1**.

Dickey DA, Fuller WA. 1979. Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association* **74**: 427–431.

Drehmann M, Juselius M. 2014. Evaluating early warning indicators of banking crises: Satisfying policy requirements. *International Journal of Forecasting* **30**: 759–780.

Gordon MJ, Shapiro E. 1956. Capital equipment analysis: The required rate of profit. *Management Science* **3**: 102–110.

Homm U, Breitung J. 2012. Testing for speculative bubbles in stock markets: A comparison of alternative methods. *Journal of Financial Econometrics* **10**: 198–231.

Im KS, Pesaran M, Shin Y. 2003. Testing for unit roots in heterogeneous panels. *Journal of Econometrics* **115**: 53 – 74.

LeRoy SF. 2004. Rational exuberance. *Journal of Economic Literature* **42**: 783–804.

Pavlidis E, Yusupova A, Paya I, Peel D, Martinez-Garcia E, Mack A, Grossman V. 2014. Monitoring housing markets for episodes of exuberance: an application of the Phillips et al. (2012, 2013) GSADF test on the Dallas Fed International House Price Database. Globalization and Monetary Policy Institute Working Paper 165, Federal Reserve Bank of Dallas.

Pesaran MH, Schuermann T, Weiner SM. 2004. Modeling regional interdependencies using a global error-correcting macroeconometric model. *Journal of Business and Economic Statistics* **22**: 129–162.

Phillips PCB, Shi SP, Yu J. 2015a. Testing for multiple bubbles: Historical episodes of exuberance and collapse in the S&P 500. *International Economic Review* **56**: 1043–1078.

Phillips PCB, Shi SP, Yu J. 2015b. Testing for multiple bubbles: Limit theory and real time detectors. *International Economic Review* **56**: 1079–1134.

Phillips PCB, Wu Y, Yu J. 2011. Explosive behavior in the 1990s NASDAQ: When did exuberance escalate asset values? *International Economic Review* **52**: 201–226.

Sargent T. 1987. *Macroeconomic Theory.* Boston: Academic Press.