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House prices and ultra-low interest rates: exploring the non-linear nexus

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Abstract

The acceleration of house price growth amidst falling interest rates to record-low levels across euro area countries between 2015 and 2021 has sparked renewed interest in the link between the two variables. Asset-pricing theory suggests that real house prices respond to changes in real interest rates in a non-linear fashion. This non-linearity should be especially pronounced at very low real interest rates. Most existing empirical studies estimate models with a constant semi-elasticity, thereby ruling out by design the potential non-linearities between house prices and interest rates. To address this issue, we estimate a panel model for the euro area countries with a constant interest rate elasticity (as opposed to a constant semi-elasticity), which is consistent with asset pricing theory. Our empirical results suggest that, in a low interest rate environment such as the period between 2015 and 2021, non-linearities in the house price response to interest rate changes are important: an increase of real interest rates from ultra-low levels could lead to downward pressure on real house prices three to eight times higher than the literature suggests.

Keywords: house prices, interest rates, elasticity, non-linearity.

JEL Codes: E43, E52, R21, R30.

Non-technical summary

The acceleration of house price growth amidst falling interest rates to record-low levels across euro area countries between 2015 and 2021 has sparked renewed interest in the link between the two variables. Annual euro area residential real estate (RRE) price growth reached 9.5% in Q4 2021—the highest growth rate observed then for over 20 years—while in half of the euro area countries RRE price growth surpassed 10%. At the same time, interest rates on mortgage loans reached a historic low during 2021 of 1.3% in nominal terms. The extent to which changes in interest rates are associated with changes in house prices is foremost an empirical question and measured by the interest rate elasticity of house prices. However, empirical estimates of the interest rate elasticity of house prices vary significantly in the literature. At the juncture of rising inflation and monetary policy reversal, elasticity estimates taking into account the specificities of a preceding ultra-low real interest rate environment are crucial for gauging the potential for house price corrections.

Previous estimates of how house prices respond to interest rates have frequently ignored the fact that asset pricing theory implies a non-linear relationship between the two. In this paper, we provide a simple model of house price determination that is able to capture meaningful non-linearities between real house prices and real interest rates and, thus, helps to improve policy makers' ability to gauge the impact of a policy-induced reversal of the (long-term) real interest rate. We also show that these non-linearities are a direct implication from asset-pricing theory.

The contribution of our paper is threefold: First, our empirical results for the euro area suggest that in the low interest rate environment of recent years, non-linearities in the real house price response to real interest rate changes do indeed exist. Second, we align our empirical specification with asset pricing theory that allows for non-linearities. Third, we show that, from a level of very low real interest rates, an increase of real interest rates by 0.1 percentage points could lead to downward pressure on real house prices in the range of -2.3% and -1.1% which is about three to eight-fold the magnitude the empirical literature would predict.

1 Introduction

The acceleration of house price growth amidst falling interest rates to record-low levels across euro area countries between 2015 and 2021 has sparked renewed interest in the link between the two variables. Annual euro area residential real estate (RRE) price growth reached 9.5% in Q4 2021—the highest growth rate observed then for over 20 years—while in half of the euro area countries RRE price growth surpassed 10%. At the same time, interest rates on mortgage loans reached a historic low during 2021 of 1.3% in nominal terms. The extent to which changes in interest rates are associated with changes in house prices is foremost an empirical question and measured by the interest rate elasticity of house prices. However, empirical estimates of the interest rate elasticity of house prices vary significantly in the literature (Iossifov, Čihák and Shanghavi, 2008; Adelino, Schoar and Severino, 2012). At the juncture of rising inflation and monetary policy reversal, elasticity estimates taking into account the specificities of a preceding ultra-low real interest rate environment are crucial for gauging the potential for house price corrections.

Previous estimates of how house prices respond to interest rates have frequently ignored the fact that asset pricing theory implies a non-linear relationship between the two. The overwhelming majority of existing empirical studies estimate semi-elasticities that do not capture these non-linearities.[1] Iossifov, Čihák and Shanghavi (2008) systematically review more than 20 country-specific and panel studies and find that reported semi-elasticities range between zero and -8, while they themselves estimate a semi-elasticity of -3.6. The authors explain this high variability by either the use of unsuitable econometric techniques or the lack of comparability of house prices in levels. Adelino, Schoar and Severino (2012) estimate a semi-elasticity of house prices at somewhere between -1.2 and -9.1, Himmelberg, Mayer and Sinai (2005) find a semi-elasticity (with respect to real rates) of less than -20, and Glaeser, Gottlieb and Gyourko (2013) put the semi-elasticity at between -1.0 and -6.8. Last, Sherlund (2020) reports U.S. national estimates of -3.2 to -3.3 and an average semi-elasticity of -2.2 on the state level, while Havranek, Kolcunova and Bajzik (2021) recently surveyed the literature and found a range of -12 to even positive numbers. Importantly, most studies presented above speak of elasticities, while, in

[1] Semi-elasticities imply a constant percentage change in real house prices for a given percentage point change in real interest rates, independent of the interest rate level. Himmelberg, Mayer and Sinai (2005), Kuttner (2012), Lim and Tsiaplias (2016), Liu et al. (2021), and Igan, Kohlscheen and Rungcharoenkitkul (2022) are notable exceptions and explicitly address non-linearities in the house price response to interest rate changes. Their contributions are discussed in greater detail in the literature sub-section further below.

fact, they are estimating semi-elasticities (common in log-linear model settings), i.e. *percentage* changes in house prices in relation to *percentage point* changes in interest rates. On average, a value for the semi-elasticity of around -3 is reported. This number implies that real house prices should drop by 3% if real interest rates rise by 1 percentage point.

In this paper, we provide a simple model of house price determination that is able to capture meaningful non-linearities between real house prices and real interest rates and, thus, helps to improve policy makers' ability to gauge the impact of a policy-induced reversal of the (long-term) real interest rate. We also show that these non-linearities are a direct implication from asset-pricing theory. The contribution of our paper is threefold: First, our empirical results for the euro area suggest that in the low interest rate environment of recent years, non-linearities in the real house price response to real interest rate changes do indeed exist. Second, we align our empirical specification with asset pricing theory by using a log-log model specification that allows for non-linearities, and which is simultaneously well-specified when using indices to estimate house price responses. Third, we show that, from a level of very low real interest rates, an increase of real interest rates by 0.1 percentage points could lead to downward pressure on real house prices in the range of -2.3% and -1.1% which is about three to eight-fold the magnitude the empirical literature would predict.

The remainder of this paper is structured as follows. In Section 2, we review the literature. Section 3 then sets up a simple asset-pricing model of house price determination that serves as our baseline for estimating an appropriate interest rate elasticity and draws conclusions on the non-linear nature of the relationships between real house prices and real interest rates from theory. Section 4 describes the data for our empirical analysis and displays stylised facts. In Section 5, we estimate our model and show evidence regarding the non-linear relationship between ultra-low real interest rates and real house prices, while we carry out robustness checks in Section 6. Section 7 analyses the marginal impact of real interest rate increases on real house prices from a level of very low real interest rates and discusses financial stability implications. Section 8 concludes.

2 Related Literature

Both the theoretical and empirical literature on house price determination is vast. We thus restrict our review to papers that look particularly at the relationship of interest rates and house prices, or at the impact of the latter two on financial stability. Theoretical models of house price determination can be separated into three strands. First, and most commonly, user cost models determine equilibrium house prices by setting the sum of the risk-free return, the depreciation and maintenance rate, several tax rates, the risk premium, and future capital gains equal to the rental cost. Second, asset-pricing models treat houses as a cash-flow yielding investment which is priced by discounting all future income streams (rents), analogous to dividend pay-outs of equities. Third, demand-supply models capture longer-term dynamics by explicitly modelling a demand function for housing and setting it equal to the housing stock.

Himmelberg, Mayer and Sinai (2005) present a user cost model and apply it to a wide range of U.S. housing markets over a time span of 25 years. The authors find that fundamentals such as changes in the real interest rate, expected inflation, expected house price appreciation, and taxes are more useful in determining correct house valuations, than the price-to-income ratio or the rental yield. They find strong evidence of non-linearities in the house price response to changes in interest rates and argue that a higher term spread is associated with lower house price growth in the future. Garriga, Manuelli and Peralta-Alva (2019) combine a user cost model of house price determination with a representative-agent general equilibrium macroeconomic model of housing which they take to U.S. data beginning in 1998. The authors estimate that during the boom prior to 2007, around 80% of the upward change in house prices were due to changes in the long-term (mortgage) interest rate. They also find evidence of asymmetry in the response of house prices with regard to the direction of equal absolute changes in the interest rate

Building on the Campbell and Shiller (1988) decomposition of the rent-to-income ratio, Campbell et al. (2009) apply the dynamic Gordon growth model to real estate and develop a model where the price-to-rent ratio can be explained by the sum of expected present discounted values of rent growth, real interest rates, and the risk premium. They find an important role for covariance among the three variables and model their expected trajectories with first-order VARs. Brunnermeier and Julliard (2008) include inflation in a similar setting to model money illusion and decompose the price-to-rent ratio into a rational and a mispricing component. They find that inflation and nominal interest rates explain a substantial amount of the variation in the mispricing of houses, real interest rates, however, do not.

Jacobsen and Naug (2005) combine a user-cost approach with a simple supply-demand model to analyse the drivers of house prices in Norway from 1990-2004 in a vector error correction specification. They find that house prices react quickly and strongly to changes in interest rates and estimate the effect of a 1 percentage point increase at -2.25% in the first quarter, and at -3.25% in the long run (semi-elasticities). The authors also find important roles for housing construction, household income, and unemployment in house price determination. In a fully-fledged supply-demand macroeconomic general equilibrium model, Favilukis, Ludvigson and van Nieuwerburgh (2017) explain the housing boom in the 2000s. They find: "First, a relaxation of financing constraints leads to a large boom in house prices. Second, the boom in house prices is entirely the result of a decline in the housing risk premium. Third, low interest rates cannot explain high home values" (p. 140). The authors ascribe a crucial role to foreign capital inflows. Similarly, Greenwald and Guren (2019) set up an equilibrium model that replicates their empirical finding that rental markets are highly frictional and segmented which, they find, implies that changing credit conditions can explain between a quarter and a half of the rise in the price-to-rent ratio during a boom.

Empirical studies, on the other hand, can be split into country-specific and country panel models. The former often use granular data and exploit variation across and within different regions while the latter rather use country-level data. Both types of models are often geared towards finding correlations, although several studies present identification strategies to derive causal inference, too. Closest to our approach in terms of research question is Jordà, Schularick and Taylor (2015) who also investigate the nexus between interest rates, house prices, and banking crises from a quantitative, historical perspective. By exploiting exogenous variation in foreign interest rates for a panel of countries with fixed exchange rate regimes, they show that loose monetary policy conditions lead to credit-driven real estate booms which, in turn, increase the probability of future financial crises. In another historical investigation, Ambrose, Eichholtz and Lindenthal (2013) use data on 355 years of house prices, inflation, interest rates, and rents in Amsterdam to investigate the behaviour of house prices relative to fundamentals. Using the approach of Campbell et al. (2009), they find that house prices can deviate from fundamentals for very long time periods, i.e. sustained periods of overvaluation, but that these periods do not necessarily qualify as bubbles or heighten financial instability. The reversion to the long-run equilibrium can take decades, and mainly occurs through prices not trough rents.

Using various panel and cross-sectional regressions, Iossifov, Čihák and Shanghavi (2008) estimate the interest rate elasticity of house prices and show that the nominal short-term interest rate, i.e. monetary policy, has a sizeable impact on real house prices. Sutton, Mihaljek and Subelyte (2017) conduct panel regressions and find that nominal short-term interest rates have a strong and persistent effect on real house prices over and above the effect of long-term rates. The authors find that, after three years, a 1 percentage point decline in short-term rates increases real house prices by 5 percent, for the United States, and by 3.5 percent for other advanced economies, implicitly estimating a semi-elasticity of between -3.5 and -5. Generally, the authors find evidence for substantial inertia in the response of house prices to changes in the interest rate, suggesting that monetary policy changes do not result in excessive and sudden changes in house prices.

Miles and Monro (2021) investigate the drivers of the house price rally in the UK over the past 30 years and find that the persistent decline in the risk-free real interest rate was likely the major driver. They estimate that, in the ultra-low interest rate environment of 2021, an increase of 1 percentage point in real rates could ultimately lead to a decline in real house prices of around 20%. Sherlund (2020) estimates interest rate elasticities of house prices on a U.S. panel data set on the national, state, metro, county and ZIP level. The author finds that house prices are more sensitive to changes in interest rates in areas with less elastic housing supply and puts the estimated interest rate semi-elasticity at around -3. Last, and very recently, two major literature reviews have been published. Duca et al. (2021) present a thorough and encompassing review of the literature on house price determinants with a special focus on the role of credit, house price expectations, financial stability, and the real economy. Havranek, Kolcunova and Bajzik (2021) present results from a meta study of 31 individual studies on the relationship between monetary policy, and thus interest rates, and house prices. They find that most *semi*-elasticity estimates are exaggerated, also because most models use short-term interest rates whereas long-term rates and liquidity measures tend to be neglected. We refer the interested reader to both excellent studies for a deeper dive into the literature.

Few studies have previously discussed the theory-implied non-linearities in the house price-interest rate relationship. Earlier examples are Himmelberg, Mayer and Sinai (2005), as discussed above, and Kuttner (2012), who discusses a theoretical "over-reaction threshold", after which house prices over-react to changes in interest rates. Lim and Tsiaplias (2016) empirically analyse Australian housing markets in a non-linear VAR setting and find that the house price-to-income ratio depend non-linearly on interest rates and that there is an interest rate threshold below which house price bubbles are probable. Liu et al. (2021) find maximum semi-elasticity estimates of mortgage rates of -2 and compare this to the user cost theory-implied non-linear response, which they find to be ten times higher. Additionally, they show that housing construction activity, i.e. price-driving supply-side factors, are very sensitive to declines in mortgage rates. Very recently, Igan, Kohlscheen and Rungcharoenkitkul (2022) put forth a random forest model of house price determination capable of capturing non-linearities and a user cost model estimated on a sample of advanced economies from 1980-2020. They confirm, under the assumption of extrapolative expectations, a non-linear relationship between interest rates and house prices. Our paper therefore fills an important gap by modelling explicitly a non-linear relationship between real interest rates and real house prices and showing that a non-linear relationship is indeed supported when estimating the model on euro area data.

3 Theory

We begin our theoretical assessment of the relationship between real house prices and real interest rates using a standard asset pricing model which links equilibrium real house prices to the present discounted value of future rental income streams:

$$P_t = \sum_{j=0}^{\infty} \frac{R_t(1+g^e)^j}{(1+\varphi)^{j+1}} = \frac{R_t}{\varphi - g_t^e}$$

where P_t is the equilibrium real house price at time t, R_t is the real rent at time t (net of maintenance costs), g_t^e is the expected growth rate of future real rents, $\varphi = i_t^e + \pi$ is the discount factor consisting of the expected future real interest rate i^e at time t, and a risk premium π. Owners expect at time t future rent growth and future interest rates to remain constant indefinitely. Thus, the rent-to-price ratio or the rental yield can be decomposed in equilibrium as

$$\frac{R_t}{P_t} = i_t^e + \pi - g_t^e. \tag{1}$$

Next, we take logs, rearrange, and receive

$$\log\left(\frac{R_t}{P_t}\right) = r_t - p_t = \log\left(i_t^e + \pi - g_t^e\right)$$

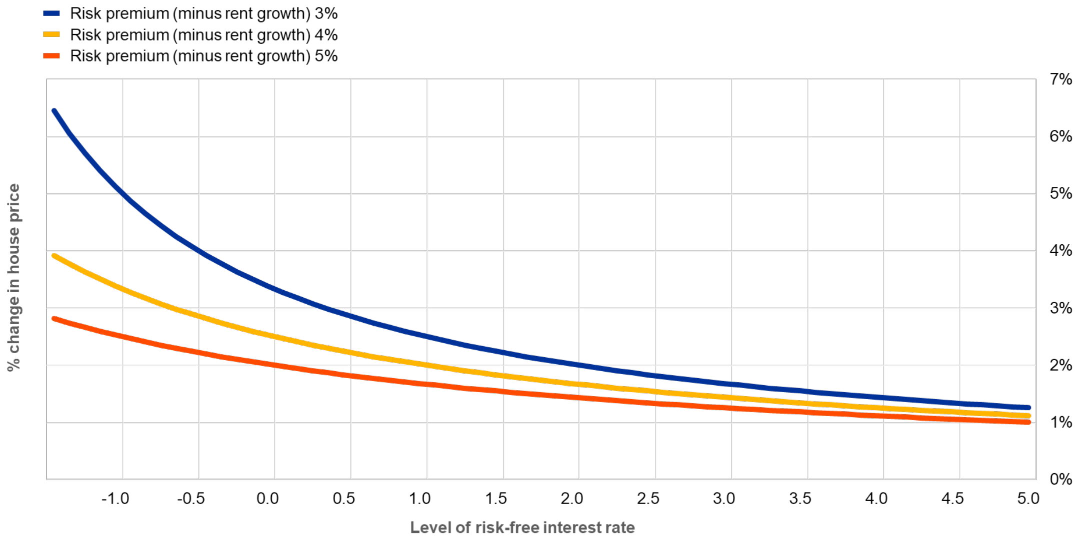
$$\Leftrightarrow p_t = r_t - \log\left(i_t^e + \pi - g_t^e\right) \tag{2}$$

Equation (1) implies that the rental yield should be equal to the sum of the risk-free interest rate and the risk premium, minus expected rent growth. The non-linear relationship between real house prices and real interest rates can be easily seen from Equation (2), which shows that log house prices can be explained by the log of current rents, and the log of the expected long-term real interest rate, the risk premium, and expected future real rent growth. From this equation, we expect real rents and the logarithmic interest rate term to have a unit elasticity (positive for the former, negative for the latter). The relationship between the log of interest rates and the log of house prices implies a non-linear relationship, i.e. a given percentage point change in the real interest rate will lead to a larger percent change in real house prices when interest rates are low. This is because a given percentage point change in the interest rate will imply a larger relative change when the level of the interest rate is low. For the purpose of this paper, we assume that no supply effects occur in the short run.

The negative unit elasticity between interest rates and house prices in Equation (2) implies interesting non-linearities that can be easily illustrated under the assumption of a constant risk premium and constant expected real rent growth. More specifically, we assume constant rent growth of $g_t^e = 1\%$, which is equal to the average long-run growth rate across euro area countries (See Section 4). Furthermore, we assume constant risk premia of either 4%, 5%, or 6%. With these assumptions we can illustrate the non-linear relationship between changes of +0.1 percentage points in the real interest rate and induced %-changes in real house prices for different initial levels of the real interest rate, as shown in Figure 1. It is obvious from the figure that real house prices respond much more to a given change in the interest rate, in a low yield environment. For example, for a 6% risk premium and 1% rent growth (red line), the house price response to a +0.1 pp change in the interest rate can vary between 1% and 3%. For lower risk premia this non-linearity is amplified: when the risk premium is 4% (blue line), the house price response to a +0.1 pp change in the interest rate can vary between 1% and 6.5%.

Equation (2) states that the log of real house prices depends on the log of current rents,

Figure 1: Theory-implied response of real house prices to a 0.1 ppt. decline in the real interest rate



and the log of the expected long-term real interest rate, expected rent growth in the future, and the constant unobservable risk premium. Since the latter three terms are encapsulated within a logarithm, and the logarithm is a non-linear function, the impact of changes in each of these three terms on house prices depends on the contemporaneous level values of the other two. In an appropriate empirical model, house price levels should be modelled as a function of rent levels, the future interest rate, future rent growth and the constant risk premium. The impact of the interest rate would depend on the contemporaneous level of rent growth and the risk premium, and the impact of rent growth would depend on the contemporaneous level of interest rates and the risk premium. Nonetheless, most empirical models estimate interest rate semi-elasticities of house prices and thus neglect this non-linearity, which is particularly important at low real interest rates (Figure 1).

3.1 Dealing with index data

Estimating Equation (1) would require level-data for house prices and rents for results to be interpretable in a sensible way. Level-data for both are sparse (see Bricongne, Turrini and Pontuch (2019) for a recent contribution), and if such data exist they usually cover only very recent periods. We must thus rely on rent and price indices when estimating models. Since price-to-rent ratios based on indices are not interpretable in levels, they also cannot be used in a linear model specification for the rental yield as in Equation (1). In the following, we show that by using empirical model specifications in line with Equation (2), which use the log rental yield or the logs of a real house price index and a real rent index, it is possible to overcome potential model misspecification and biases from using index variables. Assume r_t^{idx} and p_t^{idx} are rent and price indices, respectively, which are commonly defined as:

$$r_t^{\text{idx}} = \frac{r_t}{\overline{r}} \times 100, \quad p_t^{\text{idx}} = \frac{p_t}{\overline{p}} \times 100.$$

where $\overline{r}$ and $\overline{p}$ are the base values of rents and prices used for computing the indices. The rent-to-price ratio, i.e. the rental yield, is defined in levels as $R2P_t = \frac{r_t}{p_t}$, while for indices the ratio is

$$R2P_t^{\text{idx}} = \frac{\frac{r_t^{\text{idx}}}{p_t^{\text{idx}}}}{\overline{R2P}} \times 100 \ .$$

Now, if we take logs and rearrange, we get:

$$\log(R2P_t^{\text{idx}}) = \log\left(\frac{r_t^{\text{idx}}}{p_t^{\text{idx}}}\right) - \underbrace{\log(\overline{R2P}) + log(100)}_{=\ c\ =\ const.}$$

$$= c + \log\left(\frac{\frac{r_t}{\overline{r}} \times 100}{\frac{p_t}{\overline{p}} \times 100}\right) = c + \log\left(\frac{r_t \times 100}{\overline{r}} \times \frac{\overline{p}}{p_t \times 100}\right)$$

$$= c + \log\left(\frac{\overline{p}}{\overline{r}} \times \frac{r_t}{p_t}\right) = \underbrace{c + \log\left(\frac{\overline{p}}{\overline{r}}\right)}_{=\ a\ =\ const.} + \log\left(\frac{r_t}{p_t}\right)$$

$$= a + \log\left(\frac{r_t}{p_t}\right) = const. + \log(R2P_t)$$

Using a log-log specification as in Equation (2) in our empirical model in Section 5 will therefore recover the level information and, thus, will produce unbiased elasticity estimates. The potential distortions from using index data will simply show up in the estimated intercept term. The second advantage of using a log-log specification is that the coefficient of the logarithmic term on the right-hand side of Equation (2) can readily be interpreted as a true elasticity, i.e. a *percentage* change in house prices in response to a *percentage* change in the sum of the variables inside the logarithmic term, which include the real interest rate. This way, the non-linearity of the house price interest rate relationship is captured in a single measure. In Section 5, we estimate such an empirical model.

4 Data

We use a quarterly panel of all euro area[2] countries from 2010 to 2021. Key variables included in the database are long-term interest rates and rent and house price indices. The data are collected by the European Central Bank and come from the following data sources: MFI Interest Rate (MIR) Statistics for the interest rates, Real Estate Statistics on Residential Property Prices (RESR) for the house price indices, and Indices of Consumer prices (ICP) for housing rent indices. We start the analysis in 2010, when interest rates started to become very low, because in such conditions non-linearities in the house price response to interest rates are expected to be the most pronounced.

4.1 Dynamics of house prices and rents

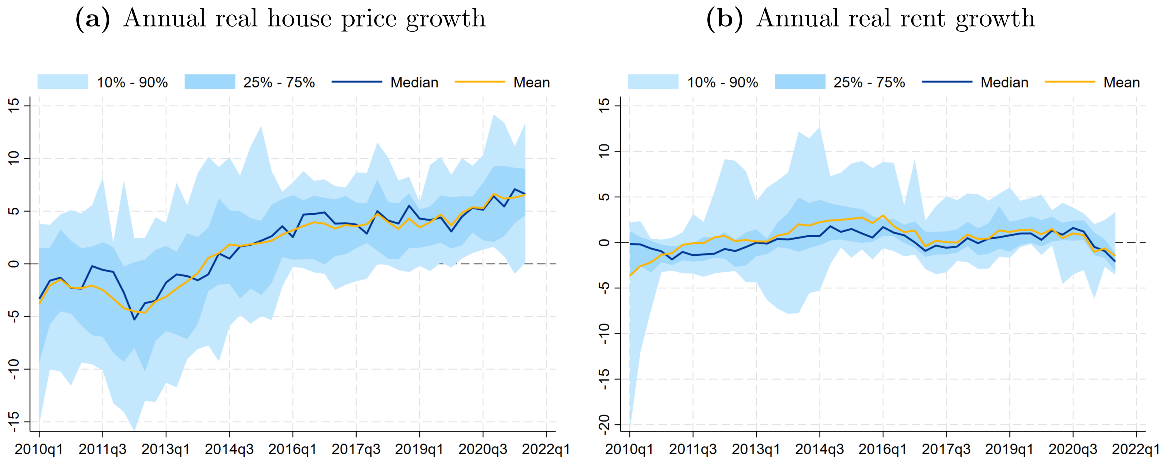
We measure real house prices with the Residential Property Prices index deflated by the HICP - Overall index. The residential property price index we use is transaction-based and covers all property types, both new and existing dwellings.[3] Real house prices have been on an upward trend for most of the period analysed (see Figure 2, left chart). The country heterogeneity is substantial, suggesting that specificities of national property markets play a substantial role.

To get an understanding of the historical evolution of real rents, we use rentals for housing from the Indices of Consumer prices data deflated using the HICP - Overall index. In contrast to house prices, real rents have not recorded strong increases since 2010 (see Figure 2, right chart). This could reflect several factors. First, house price indices are based on transactions from the

[2]These countries are Austria, Belgium, Cyprus, Germany, Estonia, Spain, Finland, France, Greece, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, the Netherlands, Portugal, Slovenia and Slovakia, but not Croatia.

[3]While RRE price data come from various sources, we selected series which have the following definitions to ensure the greatest comparability of RRE price data,: (i) the index covers the whole country, (ii) it is based on transaction value, (iii) it covers all dwelling types (with the exception of Greece, where only flats are covered), (iv) it includes new and existing properties (with the exception of Belgium, France and Slovakia, where only existing are included). The data sources are as follows: national statistical offices (Estonia, France, Slovenia), national central banks (Belgium, Cyprus, Slovakia, Italy), European Central Bank (Austria, Greece, Spain), Eurostat (Lithuania, Luxembourg, Malta, Portugal, Spain), Bank for International Settlements (Finland, Ireland, the Netherlands), and Verband Deutscher Pfandbriefbanken (Germany).

Figure 2: Real house price and real rent dynamics across countries, 2010–2021



Notes: Darker blue area denotes the interquartile range of the cross-country distribution, while the light blue area denotes the 10%-90% percentile range. Sources: LHS: Real Estate Statistics on Residential Property Prices (RESR), RHS: Indices of Consumer prices (ICP)

period under consideration. In each period only a fraction of housing stock changes hands, but the index assumes that properties which were not transacted would have a comparable market value as those which were transacted. In contrast, the rental index looks at the overall universe of rents paid in the market, both rents from new contracts concluded in the given period, but also rents from contracts which existed already before. This creates inconsistency in the treatment of old and new contracts in comparison to how they are reflected in the house prices indices. A consistent approach would require the housing rents index to cover new contracts only, but such rent indices are not readily available. Using rent indices from the HICP is therefore standard practice in the literature.[4] Second, while existing contracts can be updated periodically and in theory this way could reflect current market conditions, in practice this is rarely done. One of the reasons is the fact that the rental market is regulated in many European countries and rents covered by existing contracts cannot be increased more than by a pre-defined cap. For most of the European countries, the real annual increase of rents in the period analysed is contained, with an average of 0.55% since 2010 – but the average value over a longer horizon since Q1 1998 is closer to 1%. For our empirical section, we assume a fixed expectation on future real rent growth of 1% a year, and we consider this assumption as realistic based on the past observations.

[4]See for example Philiponnet and Turrini (2017) and Campbell et al. (2009).

4.2 Real cost of borrowing for house purchase

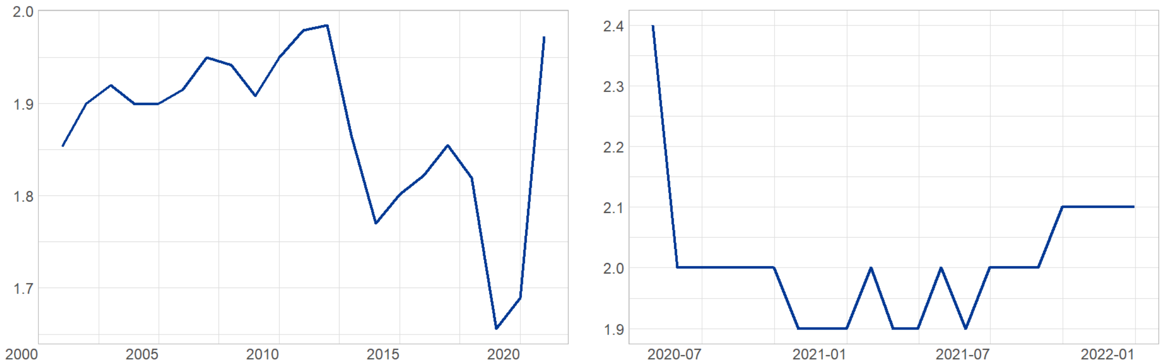
We proxy the real long-term interest rate faced by households as the difference between the cost of borrowing for households for house purchase from MFI interest rate statistics and a proxy for expected long-term inflation. The cost of borrowing for households for house purchase covers all interest payments on loans taken to finance the purchase of a property, but no other costs that may apply. The indicator is a volume-weighted average of interest rates of loans with an initial period of interest rate fixation of up to one year, and loans with an initial period of interest rate fixation over one year. Aggregation weights are based on a moving average of the previous 24 months' new business volumes.[5] Using the average cost of borrowing masks the fact that shares of fixed and floating interest rate loans vary across countries and time. Households face interest rate risk when borrowing at a variable rate, and this is likely affecting their decision-making if they expect that interest rates may change substantially during the lifetime of their mortgage loan. As such, the relationship between house prices and long-term interest rates is likely to be different in countries where fixed rates prevail than in countries where floating rate are more common (see also Section 5 on differences in the sensitivity of house prices to interest rates in countries with mostly fixed or mostly floating rates). This relationship may even change over time in countries which report a change in shares of variable interest rate loans in the period covered.

For the needs of our analysis, we must use real, and not nominal, interest rates faced by households. The choice of the deflator is non-trivial, as it must reflect long-term inflation expectations, and not observed inflation. We take a simple and transparent approach of assuming long-term inflation expectations to be at the level of the ECB's inflation target of 2%. Many other approaches could be considered, but we chose this one for its simplicity and for approximating survey data sufficiently well. The left panel in Figure 3 shows the inflation expectations of professional forecasters for the horizon of five years, collected in the period 2001-2021. Over the entire time horizon, inflation expectations averaged slightly below 1.9%, which we consider to be sufficiently close to 2%. Medium-term inflation expectations by households over a horizon of three years, collected since April 2020, seem slightly higher than long-term inflation expectations by professional forecasters, but also close to 2% (see right panel in Figure 3).

[5]See Cost-of-borrowing indicators – methodological note: `https://www.ecb.europa.eu/stats/pdf/MIR-Costofborrowingindicators-methodologicalnote.pdf?c27587d1b16c28f8b57c62de897d8e9f`.

Figure 3: Inflation expectations in the euro area, 2001–2021

(a) Long-term (5 years) inflation expectations by professional forecasters, 2001–2021 **(b)** Long-term (3 years) inflation expectations by households



Notes: LHS: Last obs. 2021. RHS: Belgium, Germany, Spain, France, Italy and the Netherlands included. Last obs. Dec 2021. Sources: LHS: Survey of Professional Forecasters (SPF), RHS: Consumer Expectations Survey (CES)

The real long-term interest rates faced by households have been decreasing over time reaching record lows in 2021 (see left-hand panel in Figure 4 below). The country heterogeneity is substantial, with some European countries having a negative real cost of borrowing already since 2015, and some remaining in positive territory, despite persistent and unprecedented decreases. This decline of real interest rates over time into ultra-low territory, at a time when real house prices were increasing robustly, allows for an analysis of the potentially non-linear relationship between the two variables. While simply reflecting correlation and not necessarily causality, the right-hand panel in Figure 4 below shows how strong increases in real house prices in the euro area coincided with the fall in the real household cost of mortgage borrowing from over 1% in 2013 to below -0.6% in 2021. The chart also suggests a non-linear relationship between real house prices and real interest rates, with house price increases particularly strong since real interest rates have fallen to an ultra-low level.

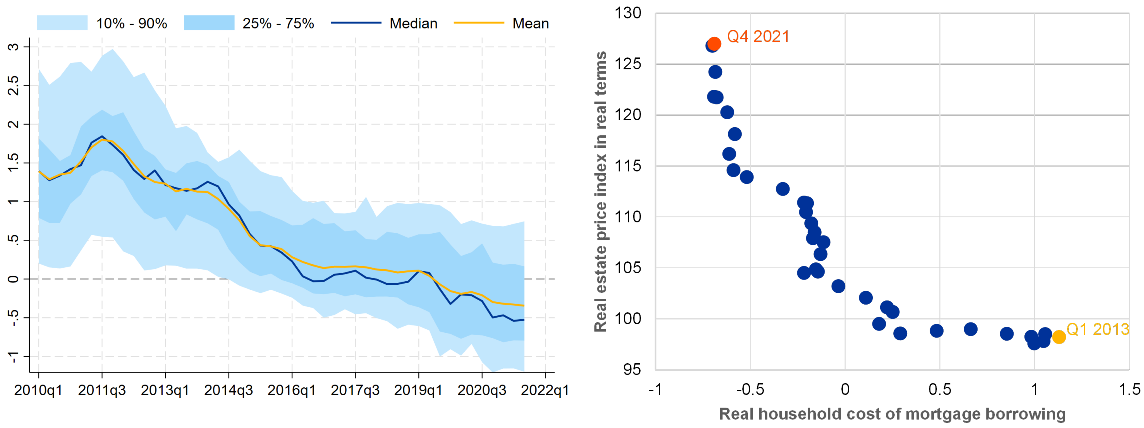
5 House prices and real interest rates

In Section 3, we developed a simple asset-pricing model of real house price determination. From Equation (2), we know that the response of real house prices to a given percentage point change in the real interest rate depends on the initial level of the interest rate, on the expectation of future rent growth, and on the risk premium. For the empirical model specification, we make the simplifying but reasonable assumption that expected rent growth and the risk premium stay

Figure 4: Stylized facts on cost of borrowing, 2010–2021

(a) Real cost of borrowing for households for house purchase across euro area countries and time

(b) Real house prices and real households cost of mortgage borrowing in the euro area since 2010



Notes: Real cost of borrowing for households for house purchase computed as nominal cost of borrowing for households for house purchase from MFI interest rate statistics minus 2% as a proxy for expected long-term inflation. Sources: LHS: MFI Interest Rate (MIR), RHS: MFI Interest Rate (MIR) Statistics and Real Estate Statistics on Residential Property Prices (RESR)

constant over time. We set $\omega = \pi - g_t^e$ with expected real rent growth $g_t^e = g_t = 1\% = const.$, which is the euro area cross-country long-term average since Q1 1998, and we set the risk premium π to the fixed value of 6%, which is in line with the literature (Jordà, 2019; Miles and Monroe, 2021).

We choose to set the risk premium constant as we wish to abstract in our analysis from cyclical variation in house prices caused by the financial cycle, i.e., by swings in sentiment and risk appetite. In a long-term historical study, Jordà et al. (2019) find that the risk premium, i.e., the difference between the risky and the safe asset, can remain remarkably constant over long periods of time, often spanning decades. The authors estimate the housing risk premium for the period between 1974 and 2015 at around 4.9% (online appendix F, Table A.10). Generally, however, risk premia tend to increase when risk-free interest rates decline. Even though it is outside of the scope of their study, the ultra-low interest rate environment of 2015–2019 will likely have had a similar effect, validating our choice to set the risk premium higher than its recent historical average. Finally, constant real rent growth expectations can be justified by very low volatility for real rent growth historically (see also Figure 2, right chart in Section 4). As a result, $\omega = 5\%$ in our baseline model specification.

To confirm the presence of non-linearities in the relationship between house prices and interest rates, we estimate two competing regression model specifications for the log of real house prices across the panel of euro area countries starting in 2010: One with the real interest rate level (constant semi-elasticity) and one with the log real interest rate term (constant elasticity) as an explanatory variable. Specifically, we define

$$log(R2P^{\text{idx}}_{\text{jt}}) = \alpha_j + \beta_0 + \beta_2 log(i^e_{\text{jt}} + \omega) + \epsilon_{\text{jt}} \tag{3.1}$$

$$\iff log(P^{\text{idx}}_{\text{jt}}) = \alpha_j + \beta^*_0 + \beta_1 log(R^{\text{idx}}_{\text{jt}}) - \beta_2 log(i^e_{\text{jt}} + \omega) + \epsilon_{\text{jt}} \tag{3.2}$$

and

$$log(R2P^{\text{idx}}_{\text{jt}}) = \alpha_j + \beta_0 + \beta_2 i^e_{\text{jt}} + \beta_3\omega + \epsilon_{\text{jt}} \tag{4.1}$$

$$\iff log(P^{\text{idx}}_{\text{jt}}) = \alpha_j + \beta^*_0 + \beta_1 log(R^{\text{idx}}_{\text{jt}}) - \beta_2 i^e_{\text{jt}} + \beta_3\omega + \epsilon_{\text{jt}} \tag{4.2}$$

where α_j are country-fixed effects, i^e_{jt} is the country-specific real household costs of borrowing, ω is a constant equalling the constant risk premium minus the long-term real rent growth (as described above), and ϵ_{jt} are the error terms.[6] The only differences in Equations (3.1) and (3.2) are that the former implicitly imposes a unit elasticity for rents, while the latter estimates the elasticity, and the sign of the coefficient on the interest rate term will be the opposite. The same applies to Equations (4.1) and (4.2). From theory, we expect for the estimation of Equation (3.2) a positive unit elasticity of real house prices with respect to real rents $\widehat{\beta_1}$ and a negative unit elasticity with respect to the interest rate term $\widehat{\beta_2}$. This constant unit elasticity results in a non-linear relationship in the response of real house prices to changes in the real interest rate: the lower the level of the real interest rate, the larger should be the response of house prices for a given percentage point interest rate change. Moreover, lower risk premia and higher expected rent growth would amplify this non-linearity.

Of the above equations, only the log-log specification in (3.1) and (3.2) results in a coefficient for the interest rate that can be interpreted as a true elasticity, and thus captures non-linearities between house prices and real interest rates. The coefficient of the log-linear specification in (4.1) and (4.2) is to be interpreted as a semi-elasticity. Below in Table 1, we present estimation results for Equations (3.1) and (4.1) with year-by-year rolling estimation start dates beginning

[6] In the following and throughout this paper, all standard error estimates are adjusted for clustering at the country level. β^*_0 is mathematically not equivalent to β_0 as it includes an additional constant that emerges when solving $log(R2P^{\text{idx}}_t)$ for $log(P^{\text{idx}}_{\text{jt}})$ as described in the theory section above.

from Q1 2010 through to Q1 2018.

Table 1: Estimation results non-linear vs. linear model panel specification, rolling starting years

	$log(R2P_t^{\text{idx}})$								
	2010+	2011+	2012+	2013+	2014+	2015+	2016+	2017+	2018+
Non-linear model									
$log(i_t^e + 5\%)$	.241*	.277*	.382**	.506**	.652***	.896***	1.02***	1.07***	1.08***
	(.111)	(.113)	(.126)	(.14)	(.149)	(.173)	(.183)	(.161)	(.152)
Intercept	4.31***	4.26***	4.09***	3.89***	3.66***	3.27***	3.07***	2.99***	2.96***
	(.188)	(.191)	(.211)	(.232)	(.243)	(.278)	(.293)	(.256)	(.239)
Linear model									
i_t^e	.038	.044*	.064*	.089**	.12**	.176***	.206***	.218***	.223***
	(.019)	(.020)	(.024)	(.028)	(.0311)	(.039)	(.041)	(.035)	(.031)
Intercept	4.7***	4.7***	4.7***	4.7***	4.71***	4.71***	4.7***	4.7***	4.69***
	(.011)	(.010)	(.009)	(.008)	(.005)	(.002)	(.0004)	(.002)	(.003)
R^2									
non-linear	0.105	0.143	0.229	0.304	0.367	0.422	0.437	0.500	0.525
linear	0.082	0.113	0.193	0.270	0.335	0.398	0.415	0.480	0.513
R^2 adjusted									
non-linear	0.104	0.141	0.228	0.303	0.366	0.420	0.436	0.498	0.523
linear	0.081	0.112	0.192	0.268	0.334	0.397	0.413	0.478	0.511
AIC									
non-linear	-1574	-1545	-1518	-1447	-1379	-1309	-1209	-1133	-981
linear	-1552	-1518	-1485	-1415	-1350	-1289	-1192	-1118	-974
BIC									
non-linear	-1570	-1540	-1513	-1443	-1375	-1305	-1205	-1129	-977
linear	-1548	-1513	-1480	-1411	-1346	-1285	-1188	-1114	-970
N	866	798	730	662	594	522	446	370	294

Note: Standard errors in parentheses, * $p<0.05$, ** $p<0.01$, *** $p<0.001$. Standard errors are robust and clustered at the country-level.

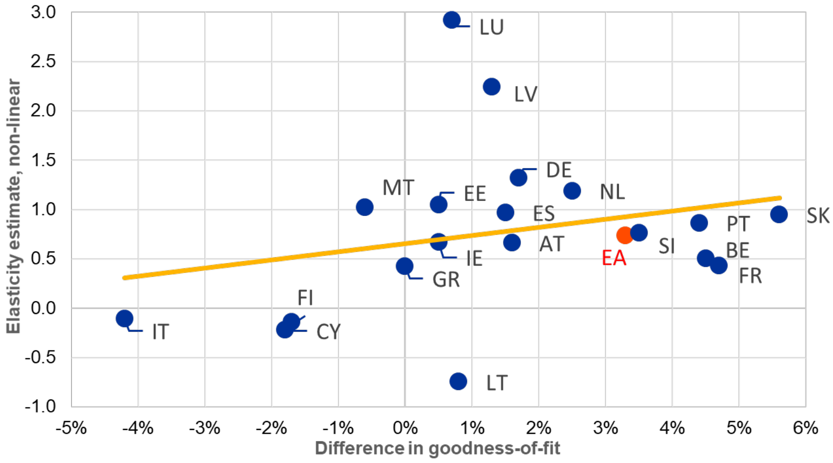
The results show that the non-linear model specification outperforms the linear one in terms of goodness-of-fit and information criteria for all starting dates. The R^2 of the non-linear model ranges from 0.11 for the starting year of 2010 up to 0.53 for the starting year of 2018. The corresponding R^2 values for the linear model are 0.08 and 0.51, respectively. Overall, the non-linear model yields a model fit that is 1.2 to 3.5 percentage points higher than for the linear model, depending on the start of the estimation sample. The difference in goodness of fit increases with the starting date reaching a maximum difference of 3.5 percentage points for the starting year 2012, after which it declines gradually to 1.2 for the starting year 2018. In addition, the AIC and BIC for the non-linear model are lower than for the linear model for all estimation start dates, confirming that the non-linear specification would be chosen over the linear one. Section 6 compares the goodness-of-fit and information criteria of the two competing models from Table 1 augmented to include additional variables controlling for demand- and supply-side factors. These augmented models confirm the findings described above.

Next, the results show that the elasticity estimate increases monotonically from 0.2 for the estimation sample starting in 2010 to 1.1 for the sample starting in 2018. This means that the elasticity converges towards the theory-implied value of unity for estimation samples that mainly cover the low interest rate environment of the past few years. At the same time, the precision of estimates also increases gradually, with the more recent starting years yielding elasticity estimates that are statistically significant at the 1 % level for samples starting after 2011.

Overall, the above results point to the existence of meaningful non-linear effects in the response of real house prices to changes in the real interest rate. The results are also economically significant. For example, applying the estimates from the non-linear model obtained for a sample starting in 2016 and using very low levels of the interest rate as of Q4 2021, we get an expected decline in euro area real house prices of around -2.41% following a 0.1 percentage point increase in real mortgage rates. The size of the response is three to eight-fold the magnitude the existing empirical literature indicates (see Section 2 for the review of the empirical estimates). Moreover, compared to the linear model specification, this is a 28 basis point stronger response (see also illustration in Section 7).

Indications of this non-linearity can also be found when repeating the same exercise as above at the country level. In Figure 5, we plot country-specific elasticity estimates (of the log-log specification starting in 2014q1) against the difference in goodness-of-fit between the non-linear and linear model specification. We find that in most euro area countries (except for in Italy, Cyprus, Finland, Malta, and Greece) the non-linear model fits the data better in recent years, with the difference in goodness of fit of up to 6% for the sample starting in 2014. Furthermore, the estimated elasticity is not too far away from the theory-implied unit value, with most country

Figure 5: Non-linear coefficient estimates and improvement in goodness-of-fit across countries, from 2014



specific estimates of the elasticity lying between 0.5 and 1.5.

Last, we estimate the log-log house price response model (3.2) by pulling the log of real rents on the right-hand side. The results are displayed in Table 2 below. We observe that for the majority of the samples, the real rent coefficient assumes a value close to unity, in line with theory as outlined in Section 3, and the interest rate coefficient estimates are very close to the previously estimated ones. Note that as expected, the sign of the coefficient on the interest rate term is now reversed compared to Table 1, due to the difference in regression specification.

Table 2: House price response panel estimation results, rolling starting years

	$log(P_t^{\text{idx}})$								
	2010+	2011+	2012+	2013+	2014+	2015+	2016+	2017+	2018+
$log(R_t^{\text{idx}})$	.942***	1.01***	1.03***	.97***	.855***	.776***	.624*	0.434	-0.0315
	-0.109	-0.1	-0.128	-0.163	-0.193	-0.244	-0.305	-0.279	-0.246
$log(i_t^e + 5\%)$	-.245**	-.277**	-.38***	-.509***	-.665***	-.911***	-1.05***	-1.11***	-1.16***
	-0.113	-0.116	-0.13	-0.145	-0.151	-0.172	-0.18	-0.154	-0.141
Intercept	0.569	0.317	0.395	0.854	1.64	2.4*	3.32**	4.31***	6.54***
	-0.596	-0.573	-0.71	-0.861	-0.978	-1.22	-1.54	-1.41	-1.27
R^2	0.447	0.471	0.505	0.508	0.499	0.507	0.5	0.561	0.612
N	866	798	730	662	594	522	446	370	294

Note: Standard errors in parentheses, * p<0.1, ** p<0.05, *** p<0.01. Standard errors are robust and clustered on the country-level.

5.1 Mortgage rate regimes

The above aggregate results on the interest rate sensitivity of house prices mask heterogeneity across euro area countries along differences in the predominant rate fixation regimes for mortgages: while patterns have changed over time towards an increased importance of fixed-rate mortgages (FRMs), mortgage markets in some countries have traditionally been dominated by FRMs contrasting with other countries where adjustable-rate mortgages (ARMs) have prevailed (see Figure 6).[7]

These differences in mortgage rate fixation regimes should be relevant for the sensitivity of real house prices to changes in real interest rates measured by the real cost of borrowing for house purchase in our analysis.[8] They entail differences in three dimensions: First, there should be different sensitivities to different terms of real interest rates, with ARMs likely being more sensitive to short-term rates and FRMs being more sensitive to longer-term rates. Second, it is to be expected that for markets with predominantly FRMs, changes in real longer-term rates affect the net present value of houses more persistently as the higher discount rate applies for a longer period into the future (see denominator in first equation in Section 3).[9] Third, while in the case of FRMs the flow of new loans is mainly affected by changes in interest rates,[10] for ARMs changes in the cost of borrowing impact the entire stock of loans. The latter may exert some second-round effects on house prices via changes in debt service which may have repercussions on demand for upgraded housing, i.e. higher demand in case of rate declines and vice-versa.[11]

To test for such difference in the interest sensitivity of different mortgage rate fixation regimes across countries, we split our sample into two country groups: one with predominantly FRM regimes including Belgium, Germany, France, the Netherlands and Slovakia (see upper

[7] MFI interest data of the Eurosystem suggest that fixed-rate contracts have dominated in Belgium (except for the first half of 2010), Germany, France, the Netherlands and Slovakia while floating rate contracts have been more important in the other euro area countries. See Albertazzi et al. (2019) for an in-depth assessment of FRMs versus ARMs among euro area banks as well as Ehrmann and Ziegelmeyer (2017).

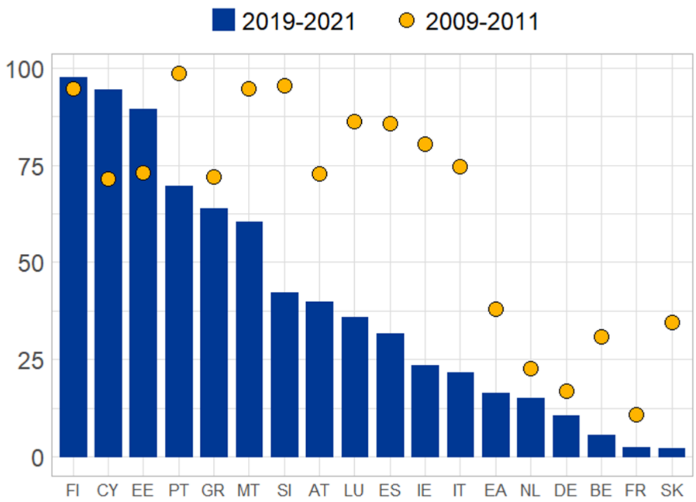
[8] As the indicator is a volume-weighted average of interest rates of loans with an initial period of interest rate fixation of up to one year, and loans with an initial period of interest rate fixation over one year (for details see Section III on data), a one percent change in the respective cost of borrowing may reflect changes in very different interest rate maturities – both across countries and over time.

[9] The degree to which this applies very much depends on the prepayment options of FRMs which differ across countries and are partially still very rigid not allowing for much flexibility.

[10] In addition, the part of the loan stock for which rate fixation expires or for which any prepayment options are exerted are likewise affected.

[11] See also Di Maggio et al. (2017) or Calza et al. (2013).

Figure 6: Shares of variable rate loans, % of newly originated mortgage loans.



Source: MFI Interest Rate (MIR) Statistics

panel in Table 3) and the other with prevailing ARM regimes (see lower panel in Table 3). We estimate the log-log specification (3.1), i.e., the non-linear specification, for the two country groups with year-by-year rolling estimation start dates.

Similar to the results for the sample comprising all euro area countries displayed in Table 1, we find for both country groups interest rate elasticities increasing in size and significance the more the estimation sample moves towards mainly covering the low interest rate environment of the years 2015–2021. This notwithstanding, estimated elasticities are notably higher and substantially more significant for the group of FRM regime countries as compared to the country group with prevailing ARMs, as Table 3 shows. Moreover, model fit as measured by the R^2 is also substantially higher for the group of FRM regime countries. These findings indeed suggest a higher sensitivity of house prices to real interest rate changes as measured by the real cost of borrowing in countries with predominantly FRMs, as one would expect.[12]

These findings point to some relevant implications for the differentiated impact of monetary policy on house prices in a low interest rate environment. In particular, they suggest that quantitative easing lowering longer-term rates may have stronger effects on house prices in countries with predominantly FRM regimes if households' inflation expectations remain anchored in the medium term; i.e. if real long-term rates likewise decline. In addition, this would

[12]It is important to recall, that real cost of borrowing reflect to a much larger degree changes in longer-term rates in the case of countries with predominantly FRM regimes than in the case of countries with ARM regimes.

Table 3: Robustness check, fixed vs. adjustable mortgage-rate regime countries

	$log(R2P_t^{\text{idx}})$								
	2010+	2011+	2012+	2013+	2014+	2015+	2016+	2017+	2018+
Fixed-rate mortgage (FRM) regime countries									
$log(i_t^e + 5\%)$	.354**	.398**	.497**	.647***	.837***	1.16***	1.41***	1.38***	1.31***
	-0.11	-0.116	-0.119	-0.127	-0.149	-0.138	-0.149	-0.168	-0.246
Intercept	3.97***	3.9***	3.75***	3.51***	3.22***	2.72***	2.33***	2.38***	2.48***
	-0.188	-0.194	-0.196	-0.206	-0.237	-0.216	-0.23	-0.256	-0.371
Adjustable-rate mortgage (ARM) regime countries									
$log(i_t^e + 5\%)$	0.13	0.172	0.288	.398*	.525**	.718**	.797***	.885***	.957***
	-0.175	-0.172	-0.197	-0.214	-0.215	-0.248	-0.233	-0.203	-0.181
Intercept	4.55***	4.49***	4.3***	4.13***	3.92***	3.61***	3.48***	3.33***	3.21***
	-0.297	-0.291	-0.33	-0.356	-0.354	-0.405	-0.378	-0.327	-0.291
R^2									
Fixed rate	0.357	0.401	0.491	0.595	0.665	0.755	0.785	0.771	0.693
Adjustable rate	0.022	0.045	0.11	0.167	0.224	0.259	0.276	0.362	0.437
N									
Fixed rate	238	218	198	178	158	138	118	98	78
Adjustable rate	628	580	532	484	436	384	328	272	216

Note: FRM countries: BE, DE, FR, NL, and SK. ARM countries: all EA excl. FRM countries. Standard errors in parentheses, * p<0.01, ** p<0.05, *** p<0.01. Standard errors are robust and clustered on the country-level.

suggest that with FRM regimes becoming increasingly important across euro area countries in the years 2015–2021 also in originally predominantly ARM regime countries,[13] these effects on house prices could gain traction across the euro area. Indeed, when incorporating the share of ARM in overall new mortgages into the log-log specification for the panel of euro area countries, we find indications for this: Interacting this share of ARM with the real cost of borrowing, the interest rate effects intensify the lower the share of ARM in overall new mortgages (see Table A.2 in the Annex); this points towards stronger effects with the increasing importance of FRM.

[13] Ehrmann and Ziegelmeyer (2017) show that the choice for ARMs is, among other factors, driven by higher interest rate spreads which is in line with the decreasing importance of ARMs observed in the more recent ultra-low interest rate environment.

6 Robustness checks

To corroborate our finding that the house price response is non-linear with respect to interest rates at very low interest rate levels, we carry out a set of robustness checks. Specifically, we test whether our result that models capturing non-linearity have a higher goodness-of-fit than linear models hold if we i) incorporate demand-side factors into our regression, ii) include a supply-side factor, and iii) check for different risk premia.

First, we assess whether we can find empirical evidence for the non-linearity when including a standard set of other demand-side factors into the regression. We are interested in whether the non-linearity in the relationship between interest rates and house prices has a measurable effect on the response *over and above* the impact of other variables that affect housing demand. Second, we seek to analyse how the role of interest rates has changed over time in our sample. We would expect interest rates to play a larger role in the house price determination at lower levels. Table 4 and Table 5 present regression results from our log-log and log-linear model specification, respectively, when including the unemployment rate U_t, the household credit-to-GDP ratio HHC_t, real GDP per capita in PPP RGDP_t, the euro area AA NFC bond spread AA_t, and the population share of adults aged 20 to 64 POPS_t.

First, comparing the log-log (Table 4) with the log-linear (Table 5) specification, we see our previous finding confirmed. The non-linear model outperforms the linear model in terms of goodness-of-fit, also when additional demand-side factors are incorporated into the specifications. The unadjusted and adjusted R^2 of the non-linear models are around 1 percentage point higher than those of linear models for most of the estimation samples. As expected, and in line with the difference in goodness-of-fit of more parsimonious models applied in Section 5, this difference is more pronounced the longer the estimation sample reflecting the increasing divergence of a non-linear relationship from a linear approximation. Moreover, the *AIC* and *BIC* are lower for the non-linear model than for the linear model for all estimation start dates, suggesting that the non-linear specification should be chosen.

Second, and in line with our expectations, we observe in both tables that the overall explanatory power of the model increases drastically when including other demand-side factors. This holds particularly for the earlier starting periods. We also see that interest rates are significant for samples starting around the time when real rates hit the ultra-low environment of around or

Table 4: Robustness check, demand-side factors, log-log specification

	$log(R2P_t^{\text{idx}})$								
	2010+	2011+	2012+	2013+	2014+	2015+	2016+	2017+	2018+
$log(i_t^e + 5\%)$	0.193	0.138	0.113	0.187	0.315	.516**	.651***	.711***	.625***
	-0.156	-0.161	-0.172	-0.188	-0.191	-0.208	-0.211	-0.209	-0.205
$log(U_t)$	.183*	.192**	.178**	0.131	0.083	0.039	0.015	-0.023	-0.014
	-0.093	-0.088	-0.083	-0.078	-0.069	-0.06	-0.052	-0.046	-0.04
$log(\text{HHC}_t)$	-.271***	-.265**	-.228*	-0.184	-0.175	-0.184	-0.247	-0.252	-.31**
	-0.089	-0.092	-0.112	-0.143	-0.165	-0.185	-0.188	-0.155	-0.12
$log(\text{RGDP}_t)$	-0.275	-0.345	-0.325	-0.282	-0.249	-0.287	-0.427	-.408*	-.438**
	-0.257	-0.244	-0.243	-0.261	-0.28	-0.286	-0.276	-0.218	-0.172
$log(\text{AA}_t)$	-0.014	-0.00437	.034***	.054***	.055***	.046***	.039***	.030***	.030***
	-0.026	-0.021	-0.009	-0.007	-0.008	-0.009	-0.007	-0.006	-0.006
$log(\text{POPS}_t)$	-2.3	-1.62	-0.476	0.725	1.93	2.75	3.28*	3.93**	5.06**
	-1.51	-1.69	-1.78	-1.95	-2.06	-2.02	-1.83	-1.73	-1.77
Intercept	4.92***	5.51***	5.78***	5.96***	6.32***	6.71***	7.56***	7.86***	8.9***
	-1.38	-1.35	-1.35	-1.37	-1.27	-1.2	-1.14	-0.848	-0.802
R^2	0.314	0.327	0.362	0.411	0.477	0.549	0.592	0.629	0.672
R^2 *baseline*	0.105	0.143	0.229	0.304	0.367	0.422	0.437	0.5	0.525
R^2 *adjusted*	0.31	0.321	0.357	0.405	0.472	0.544	0.586	0.623	0.665
R^2 *adj. baseline*	0.104	0.141	0.228	0.303	0.366	0.42	0.436	0.498	0.523
AIC	-1814	-1750	-1669	-1567	-1499	-1441	-1351	-1238	-1079
BIC	-1786	-1722	-1642	-1541	-1473	-1416	-1327	-1215	-1057
N	857	789	721	653	585	513	437	361	285

Note: Standard errors in parentheses, * p<0.1, ** p<0.05, *** p<0.01. Standard errors are robust and clustered on the country-level. § Goodness-of-fit of interest rate-only non-linear baseline model presented in Table 1.

below zero in 2015 and 2016. Pairing these findings with the fact that the increase in goodness-of-fit from adding other demand-side variables for later sample starting points is less pronounced, we conclude that interest rates play a more important role *over and above* other demand-side factors with the beginning of the ultra-low interest rate environment, thereby corroborating one of our study's main findings.

The signs of the control variables are mostly as expected and in line with the literature. A higher household debt-to-GDP ratio and higher GDP per capita push the rental yield down, i.e.

Table 5: Robustness check, demand-side factors, log-level specification

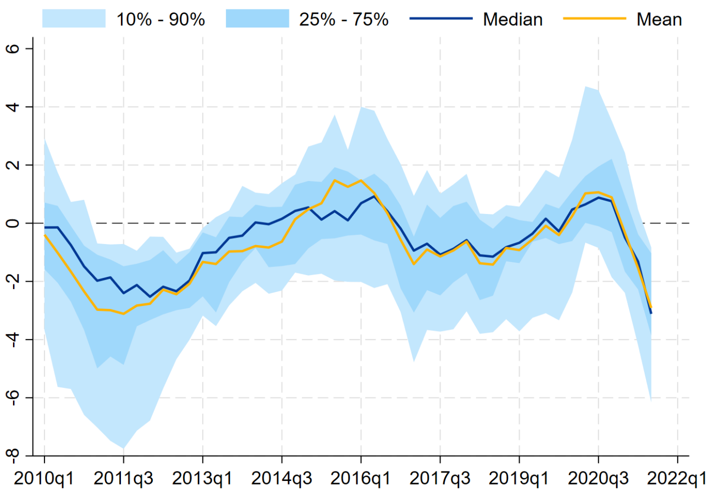
	$log(R2P_t^{\text{idx}})$								
	2010+	2011+	2012+	2013+	2014+	2015+	2016+	2017+	2018+
$log(i_t^e + 5\%)$	0.0227	0.0134	0.00915	0.0231	0.0513	.0989**	.131***	.144***	.128***
	-0.0257	-0.0266	-0.0292	-0.0344	-0.0366	-0.042	-0.0429	-0.0418	-0.0404
$log(U_t)$	.197**	.207**	.194**	.148*	0.095	0.0439	0.0176	-0.0208	-0.0129
	-0.0932	-0.0882	-0.0824	-0.0773	-0.0692	-0.061	-0.0519	-0.0446	-0.0389
$log(\text{HHC}_t)$	-.287***	-.278***	-.239*	-0.196	-0.188	-0.204	-0.274	-.283*	-.338**
	-0.0884	-0.0939	-0.115	-0.148	-0.17	-0.189	-0.192	-0.159	-0.122
$log(\text{RGDP}_t)$	-0.27	-0.336	-0.317	-0.271	-0.236	-0.274	-0.424	-.415*	-.449**
	-0.26	-0.246	-0.246	-0.264	-0.282	-0.286	-0.273	-0.213	-0.167
$log(\text{AA}_t)$	-0.00756	0.00143	.0361***	.0529***	.0546***	.0464***	.0387***	.03***	.0294***
	-0.0274	-0.0214	-0.0096	-0.00735	-0.00815	-0.00843	-0.00695	-0.00577	-0.00589
$log(\text{POPS}_t)$	-2	-1.32	-0.212	0.953	2.11	2.91	3.43*	4.07**	5.11***
	-1.47	-1.66	-1.76	-1.94	-2.05	-2	-1.77	-1.65	-1.71
Intercept	5.37***	5.85***	6.07***	6.36***	6.9***	7.64***	8.78***	9.22***	10.1***
	-1.29	-1.26	-1.26	-1.29	-1.22	-1.15	-1.12	-0.814	-0.667
R^2	0.3	0.317	0.355	0.401	0.466	0.542	0.589	0.627	0.671
R^2 *baseline*	0.082	0.113	0.193	0.27	0.335	0.398	0.415	0.48	0.513
R^2 *adjusted*	0.3	0.312	0.35	0.395	0.461	0.537	0.583	0.62	0.664
R^2 *adj. baseline*	0.081	0.112	0.192	0.268	0.334	0.397	0.413	0.478	0.511
AIC	-1796	-1738	-1661	-1556	-1487	-1434	-1348	-1236	-1078
BIC	-1768	-1710	-1634	-1529	-1460	-1408	-1323	-1213	-1056
N	857	789	721	653	585	513	437	361	285

Note: Standard errors in parentheses, * p<0.1, ** p<0.05, *** p<0.01. Standard errors are robust and clustered on the country-level. § Goodness-of-fit of interest rate-only non-linear baseline model presented in Table 1.

they raise house prices all else equal, confirming the results of Greenwald and Guren (2019).[14] In contrast, the unemployment rate impacts the rental yield positively for the longer estimation samples, i.e. reducing house prices, which is similar to what Sutton et al. (2017) find. The unemployment rate in more recent estimation samples and real GDP per capita in the longer estimation samples are insignificant, which has also been reported in the literature. For example, Iossifov, Čihák and Shanghavi (2008) decided to drop these variables from their preferred model as they were insignificant in their specifications. Higher bond spreads push up the rental yield,

[14] We also run the same regression on a core euro area country subset from which we exclude the eastern countries Estonia, Lithuania, Latvia, Slovenia, and Slovakia. The results are slightly improved still. Especially, the population variable does not change sign at significant confidence towards the end of the rolling window and the overall difference in goodness-of-fit between both model specifications is more pronounced.

Figure 7: Dynamics of real housing capital stock, percentage, y-o-y growth rate



Source: MFI Interest Rate (MIR) Statistics.

i.e. they reduce house prices all else equal, which is in line with expectations. The population share variable is insignificant for the majority of the estimation periods and starts being positive towards the end of the estimation period, implying a negative impact on house prices. While this may be in contrast with intuition and some findings in the literature,[15] there are also studies which find no significant effect of demographics on house prices.[16]

Next, we include a supply-side factor into the regression with the aim of checking if the evidence of the non-linearity in the relationship between interest rates and house prices remains unaffected. We use estimates of the real housing capital stock[17] as a proxy for the supply of housing. Overall, growth of the real housing capital stock is persistent and not too volatile, oscillating in a corridor of around +/-2% on average in euro area countries (see Figure 7). We include the lagged real housing capital stock in logs both in the log-log and log-linear regression specifications in Table 6.

As expected, also the specification including the supply of housing among the explanatory variables confirms our main finding that the constant elasticity model capturing non-linearity in the relationship between house prices and interest rates outperforms the constant semi-elasticity model implying a linear relationship between these two variables. The unadjusted and ad-

[15]See for example Philiponnet and Turrini (2017).
[16]See for example Annett (2005).
[17]Dwellings of households in domestic currency from the Quarterly Sector Accounts (QSA) database, deflated by the HICP - Overall index.

Table 6: Robustness check, housing stock supply, log-log specification

	$log(R2P_t^{\text{idx}})$								
	2010+	2011+	2012+	2013+	2014+	2015+	2016+	2017+	2018+
Non-linear model									
$log(i_t^e + 5\%)$	.247**	.296**	.401***	.512***	.651***	.882***	1.01***	1.08***	1.1***
	-0.117	-0.12	-0.13	-0.141	-0.148	-0.168	-0.174	-0.161	-0.154
$log(rre\_hss_{t-1})$	0.002	0.004	0.005	0.004	0.004	0.006	.006*	0.003	0.004
	-0.004	-0.004	-0.005	-0.004	-0.004	-0.004	-0.003	-0.007	-0.007
Intercept	4.3***	4.23***	4.06***	3.88***	3.66***	3.3***	3.08***	2.98***	2.93***
	-0.198	-0.201	-0.216	-0.232	-0.241	-0.271	-0.279	-0.255	-0.242
Linear model									
i_t^e	.039*	.048**	.068**	.090***	.12***	.174***	.205***	.221***	.228***
	-0.021	-0.022	-0.024	-0.028	-0.031	-0.037	-0.039	-0.035	-0.032
$log(rre\_hss_{t-1})$	0.001	0.004	0.005	0.004	0.005	0.007	.007*	0.004	0.005
	-0.004	-0.004	-0.005	-0.004	-0.004	-0.004	-0.003	-0.007	-0.007
Intercept	4.68***	4.68***	4.68***	4.68***	4.67***	4.67***	4.68***	4.67***	4.67***
	-0.012	-0.011	-0.01	-0.008	-0.004	0	-0.004	-0.006	-0.007
R^2									
non-linear	0.106	0.15	0.239	0.313	0.376	0.441	0.456	0.502	0.53
linear	0.083	0.12	0.204	0.279	0.346	0.419	0.436	0.484	0.52
non-linear baseline	0.105	0.143	0.229	0.304	0.367	0.422	0.437	0.5	0.525
linear baseline	0.082	0.113	0.193	0.27	0.335	0.398	0.415	0.48	0.513
R^2 *adjusted*									
non-linear	0.104	0.148	0.237	0.31	0.374	0.438	0.454	0.499	0.527
linear	0.08	0.118	0.202	0.277	0.344	0.417	0.433	0.481	0.517
non-linear baseline	0.104	0.141	0.228	0.303	0.366	0.42	0.436	0.498	0.523
linear baseline	0.081	0.112	0.192	0.268	0.334	0.397	0.413	0.478	0.511
N	663	607	551	495	439	383	327	271	215

Note: Standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01. Standard errors are robust and clustered on the country-level.

justed R^2 of the non-linear model are 1.2-3.7 percentage points higher than the R^2 of the linear model.

Overall, however, incorporating the supply of housing into the model improves the goodness-of-fit only slightly. While both unadjusted and adjusted R^2 increase when the proxy for the housing supply is included both in the log-log and the log-linear regressions, the coefficients on the housing supply are mostly insignificant. This is unsurprising, as the supply of housing can be considered given in the short-term due to construction delays. This finding is also in line with the literature – Arestis & González (2014) show that real residential investment contributes to explaining prices in OECD countries only in the long-term, and not in the short-term.

As a final robustness exercise, we re-estimate our baseline log-log regression equation with different risk premia. Table 7 directly sets the respective goodness-of-fit measures into comparison.

Table 7: Comparison of goodness-of-fit for different risk premia, both specifications

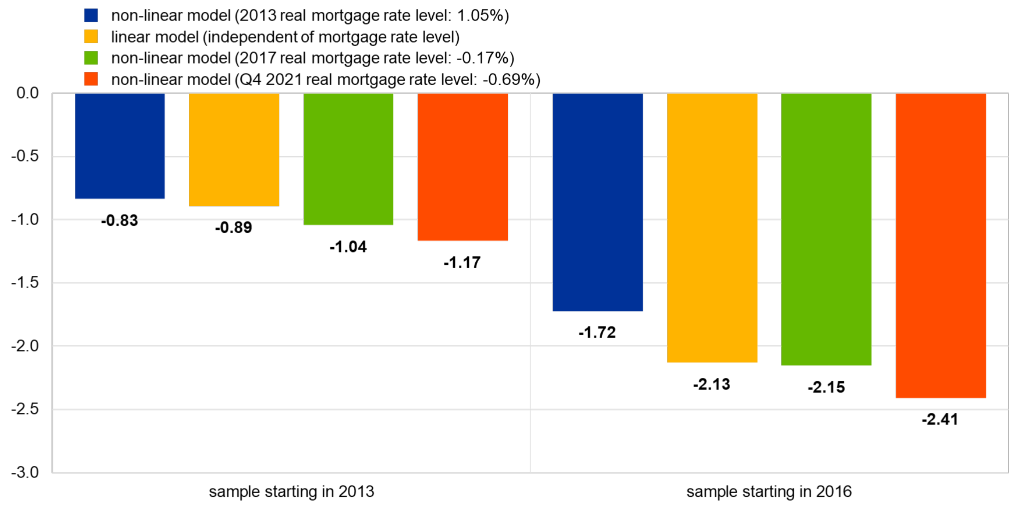
	2010+	2011+	2012+	2013+	2014+	2015+	2016+	2017+	2018+
$log(i_t^e + 2\%)$	0.132	0.175	0.263	0.333	0.391	0.434	0.449	0.507	0.524
$log(i_t^e + 3\%)$	0.118	0.159	0.247	0.320	0.382	0.431	0.447	0.507	0.528
$log(i_t^e + 4\%)$	0.110	0.149	0.236	0.311	0.373	0.426	0.441	0.503	0.527
$log(i_t^e + 5\%)$	0.105	0.143	0.229	0.304	0.367	0.422	0.437	0.500	0.525
$log(i_t^e + 6\%)$	0.102	0.138	0.224	0.299	0.363	0.418	0.434	0.497	0.523
i_t^e	0.082	0.113	0.193	0.270	0.335	0.398	0.415	0.480	0.513
N	866	798	730	662	594	522	446	370	294

We find that the improvement in goodness-of-fit of the non-linear model over the linear model holds across all risk premia, confirming that the outperformance of the non-linear model vis-a-vis the linear model is independent of the risk premium assumed, as implied by theory. The improvement is visible especially for earlier starting dates and at lower risk premia which is expected from theory as the resulting logarithms will have steeper and more pronounced curvature at low interest rate levels, implying stronger non-linearity. The fact that the models with lower risk premia yield the highest model fit therefore is another indication that the non-linearity is particularly important in periods of very low interest rates.

7 The marginal impact of changes in real interest rates on house prices

The negative non-linear relationship between real house price growth and changes in real interest rates has important implications in a low real interest rate environment. First, a bigger fraction of observed real house price growth between 2015 and 2021 may be due to declines in real borrowing costs for households. Second, the potential downward pressure on real house prices

Figure 8: Estimated % change in real house prices after a 0.1 ppt. increase in the real interest rate

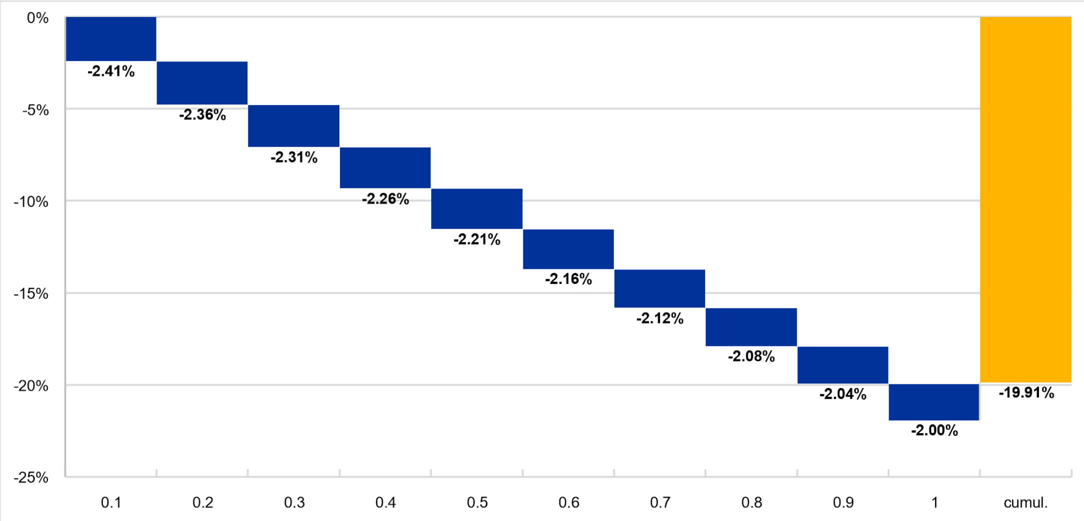


Note: The mortgage rate is at euro area level.

from rising real interest rates from such a low level as observed between 2015 and 2021 might be substantially larger than what conventional econometric models would suggest. We use our panel elasticity estimates from Table 2 in Section 5 and Q4 2021 aggregate euro area data to predict the marginal house price response to a hypothetical 0.1 percentage point increase (over one quarter) in the real household cost of borrowing for house purchases. Figure 8 displays the results for the estimated models using data starting in 2013 and in 2016.

There are several take-aways from Figure 8. First, the estimated house price response depends strongly on the sample starting date. Starting the estimation sample in 2016 when rates began to venture into ultra-low territory, roughly doubles the expected marginal response from the non-linear log-log model specification compared to a model estimated on a sample starting in 2013. This is reflective of the heightened sensitivity of house prices with respect to changes in interest rates estimated when interest rates are very low. It is important to note, however, that the estimated house price response is *marginal* with respect to the simulated 10 basis point increase in the real cost of borrowing. Every successive 10 basis point increase will have a slightly lower impact overall, due to the non-linear nature of the relationship. Figure 9 displays marginal house price decreases for ten steps and shows that the cumulative decline in house prices would be -19.9% instead of a simple multiplication of ten of the first -2.41% decrease in Q4 2021.

Figure 9: Marginal house price response, 10 basis points increments, in Q4 2021



Note: Log-log model specification estimated from Q1 2016.

Second, Figure 8 shows that the size of the estimated house price response depends crucially on the level of the real interest rate at which its change occurs. In line with the non-linear relationship, the response is accentuated when interest rates rise from a lower level like in 2017 or 2021, as shown above. Third and last, the figure shows the response difference between a linear and non-linear model for the different estimation samples and initial interest rate levels. Obviously, the linear response is independent of the interest rate level. As of Q4 2021, where the euro area average real household cost of borrowing stood at -0.69%, this would result in a difference of around 25 basis points for both estimation start dates between our non-linear specification and a conventional linear one.

In summary, based on the panel elasticity estimates above and the Q4 2021-level of real interest rates, an increase in real interest rates by just 0.1 percentage points within one quarter could lead to downward pressure on real house prices of between -2.4% and -1.2% across euro area countries, depending on which estimation start date is chosen to obtain the elasticity estimates. Compared to the literature's average semi-elasticity estimate of -3, which implies a -0.3% change in house prices for a 0.1pp increase in the real interest rate, we retrieve a house prices response that is four to eight-fold as strong in an environment of very low real interest rates. When compared to the linear model on the same estimation sample, the difference (i.e. between the red and yellow bars in Figure 8 above) in the impact on real house prices of a 0.1pp change in the real interest rate comes out to 28 basis points at the end of the sample.

8 Conclusion

In this paper, we have shown that most prior studies of the relationship between real interest rates and real house prices disregard basic implications from asset-pricing theory, i.e. the non-linearity between the two factors, and, as a result, produce mis-specified estimates. Drawing on insights from standard asset-pricing theory, we propose a simple model to explicitly address the non-linear nature of the relationship in an empirical setting.

We find that, in a low interest rate environment such as the period between 2015 and 2021, non-linearities in the house price response to interest rate changes are important as evidenced by better performance of the model that allows to capture non-linearities (a model with a constant elasticity) compared to the model which allows to capture linearity only (a model with constant semi-elasticity). Taking the ultra-low interest rate level of Q4 2021 as an example, an increase of real interest rates by 0.1 percentage points could lead to downward pressure on real house prices in the range of -2.4% and -1.2% which is about four to eight-fold the magnitude the literature would predict.

Our findings are highly relevant for policy makers as sharp declines in house prices, especially after long periods of credit-sustained expansion, have historically been frequently associated with banking crises (Jordà, Schularick & Taylor, 2015; Baron & Dieckelmann, 2022). A sharp increase in the real household cost of borrowing or, more generally, of real interest rates, could affect banks' financial health either through increases in difficulties of households to repay their loans and a resulting rise in non-performing loans or through a medium-term bank-profitability channel, depending on the country's mortgage rate regime. At the juncture of rising inflation and monetary policy reversal, elasticity estimates taking into account the specificities of a preceding ultra-low real interest rate environment are crucial for gauging the potential for house price corrections.

From our analysis, we derive several avenues for further research. First, data on rents for new contracts are needed to correctly estimate the rent elasticity. Second, empirical models of house price determination have been notoriously bad in explaining house prices along the lines laid out by theory. While we offer a reconciliation at the ultra-low interest rate level, a more general enquiry into the myriad of factors that drive house prices is needed. The very recent study by Duca et al. (2021) is an excellent starting point for such an agenda. Third, and unlike its counterpart in the equity market, the housing risk premium is poorly understood. Further research into how country-specific institutional factors or how the financial cycle (through cost of credit and credit supply) and sentiment (through extrapolative expectations) are drivers of fluctuations in risk premia would greatly improve the accuracy of models of house price determination that follow an asset-pricing approach.

Annex

Table A1: Summary statistics of key variables used

	N	Mean	SD	IQR	p25	p75	min	max
Annual real RRE price growth	902	1.56	5.88	6.83	-1.37	5.47	-21.33	19.78
Annual real rent growth	912	0.5	4.13	3.08	-1.28	1.8	-26.88	22.65
Real interest rate	876	1.09	1.73	2.14	0.1	2.24	-9.92	5.73
Unemployment rate	912	9.52	5.02	5.61	6.03	11.65	3.08	27.92
Household credit to GDP ratio	893	58.2	25.39	24.45	41.26	65.71	19.89	131.53
Real GDP per capita in PPP	912	30.41	13.73	11.94	22.12	34.06	14.22	79.94
EA AA NFC bond spread AA	912	83.88	35.15	23	63.5	86.5	51	222
Population share of adults aged 20 to 64	912	0.61	0.02	0.03	0.59	0.62	0.55	0.66
Annual real housing capital stock growth	893	-0.84	2.53	2.43	-2.02	0.41	-12.81	21.54

Note: Summary statistics computed on a sample of EA countries over 2010-2021 period. SD denotes standard deviation, IQR interquartile range, p25 and p75 denote lower and upper quartile, respectively. Growth rates, rates, ratios and shares are in percentages, while spread is in basis points.

Table A2: Fixed vs. adjustable mortgage-rate regime countries, alternative specification, from 2010

	$log(P_t^{\text{idx}})$		
	(1)	(2)	(3)
$log(R_t^{\text{idx}})$	.942***	.906***	.964***
	(.109)	(.0969)	(.0936)
$log(i_t^e + 5\%)$	-.245**	-.181	-.39***
	(.113)	(.116)	(.127)
Ratio of adjustable-rate mortgages		-.129	-1.05**
		(.115)	(.454)
$\log(i_t^e + 5\%) \times$ ratio of adjustable-rate mortgages			.529*
			(.254)
Intercept	.569	.699	.792
	(.596)	(.557)	(.492)
R^2	0.447	0.464	0.498
N	866	866	866

Note: Standard errors in parentheses, * p<0.1, ** p<0.05, *** p<0.01. Standard errors are robust and clustered on the country-level. Estimated with data beginning in 2010.

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