Global housing markets, machine learning, and the emergence of the safe asset, 1465-2024*

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Abstract

Combining machine learning approaches with new historical primary data and econometrics, this paper is the first to comprehensively reconstruct the truly "long cycles" in global real estate, from the 15th century to the present, and its fundamental properties. Contrary to existing consensus, I find that the ongoing "housing boom" of the 21st century actually originates in the Great Depression and that it is closely tied to a secular trend decline in mortgage rates that has unfolded over centuries. Real estate returns are strongly trend stationary, and the two greatest global housing crashes since the Renaissance occurred in 2008 and the Thirty Years War, with the latter date marking the inception point of a secular decline in mortgage rates and with idiosyncratic risk in housing being remarkably stable since this point in time. Indeed, housing excess returns now add to evidence that it was the particular period around 1648 that first witnessed the emergence of sovereign debt as the "safe asset", which around then began its divergence from the rest of the asset universe.

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1 Introduction

The early 21st century housing boom reversed spectacularly with the 2008 real estate bust in the U.S. and other advanced economies. Unusually low interest rates, financial innovation, and demographic trends are among the factors alleged to have resulted in the most intense and long-lived real home price appreciation from at least the 1980s which drove real house prices sharply away from underlying fundamental value.

Yet, as of early 2025, advanced economy real house prices have not just resumed but even surpassed the previous secular peak – despite the end of zero-bound policy interest rates, a reduction of the baby-boomer cohort pressures, and much more stringent regulation of mortgage products.

In light of the 2008 housing crisis, much research has attempted to better understand the credit and real estate-specific longer-run factors that account for the most recent "boom and bust" cycle – as well as longer-run return patterns in real estate, both as a separate asset class and in connection to other "safe" and "riskier" asset classes. But major controversies remain – including the question whether housing outperforms other asset classes over the long run, and whether the recent housing boom in advanced economies represents a persistent financial bubble, driven perhaps by ultra-low policy rates.

However, existing housing research falls short on a more general dimension. Since at least the Renaissance, it is known that residential real estate consistently represents the single largest financial asset, continuing into the present. With typical depreciation rates of 1-3% p.a., housing represents an unusually long-lived asset; historically, it was standard in Europe, for instance, to calculate with 200 year life expectancies for residential buildings.[1] Against this backdrop, the truly secular financial performance of housing – together with its longer-run *relative return* in the asset universe – by design favors a long-run asset pricing approach, but remains critically understudied in this dimension.

Though the most recent century of global housing markets is increasingly well studied as of late, it remains unclear how the truly secular trends have evolved. Near exclusively, even existing "long-run" investigations begin at best in the late 19th century and thus typically feature on average just a handful of property-level market transactions. This is problematic not least because standard econometric analysis – structural break tests that are commonly used to identify "inflection points" in asset pricing, or stationarity tests – demonstrably lack statistical power even for samples "only" spanning 100-150 years. This has been appreciated for related asset classes, and led to important revisions of stylized facts – most recently for benchmark interest rates.[2]

One of the key propositions of this paper therefore is that reconstructing the very long run empirics

[1] On capital stock and financial asset composition estimates over time see Goldsmith (1985), and more recent data in Schmelzing (2025); on historical depreciation rates, see Voigt (1901, 5).

[2] See the very recent example for real interest rates (Rogoff et al., 2024). The authors show that the consensual views on interest rate inflections and econometric properties are meaningfully qualified when long sample date is introduced – including stationarity and structural break features.

of this asset class can add significant new evidence to fundamental asset pricing debates – debates focusing on the properties of real estate performance itself, as well as those assessing its relative performance in the wider asset pricing universe over time. While measurement bars are thought to be higher in residential real estate relative to alternative asset classes, one advantage is that real estate represents an "ancient" asset class with comprehensive long-run documentation, including primary archival sources. Meanwhile, the reconstruction of aggregate real estate return indices lends itself almost ideally to the exploitation of recent methodological leaps in machine learning, with a range of known co-variates for house prices being available in the historical literature for manual reconstructions.
This paper will engage in such a holistic fusion of primary source and machine learning methodologies, to arrive at new multi-century house price and total return series for key advanced economies, as well as the "global" level. Specifically, I focus on four key advanced economies – the U.S., the U.K., the Netherlands, and Germany – for which I reconstruct house prices via key long-run co-variates of housing prices in modern times, including the reconstruction of harmonized building cost indices over centuries. Together, these four countries account for over 50% of advanced economy GDP over time and for the first time allow a truly secular analysis of "long cycles" in real estate. For Germany, where the primary source situation is unusually favorable, I also construct a new archival source-based repeat-sales index for real and nominal German house prices (methodologically resembling the modern benchmark Case-Shiller index), as well as total returns from the late 15th century: here we are covering hundreds of identical residential properties that can can be chained into long series of repeat-sales chronologies via primary source *Häuserbücher*.

I then proceed with analysis. This paper is the first to reconstruct and analyze the truly "long cycle" dynamics in global real estate since the Renaissance. I find that a first broad-based housing boom spanned the 150 years between the Peace of Westphalia and the French Revolution. Afterwards, global house prices receded through the 19th century, and finally bottomed out globally at the end of the Great Depression. The ongoing, modern secular "housing boom" originates in a major inflection point at the end of the Great Depression, when global house prices fell back to 16th century lows. I show that only in the early 2000s, in fact, did real global house prices surpass previous high watermarks reached in the late 1700s again.
In the econometric section, we can confirm that real house prices are a strongly trend stationary variable, and show very few structural breaks over the very long run. This applies to both the new machine learning-generated, as well as the primary source-based indices, and across countries and global levels.

Reconstructing residential real estate total returns has created meaningful measurement challenges even for recent data. Zooming into the case of Germany for the return side, I utilize a large body of primary sources and find that excess housing returns display a "U-shaped" trajectory over the centuries, with strong positive spreads over government assets prior to the mid-16h century, followed by a slump during the 17th century, before embarking on an accelerating trajectory since around 1650: since then, excess housing returns have gradually risen and by the 1800s approached

the "modern" levels that existing literature estimates at 4-6% p.a. Individual homeowners steadily improved absolute and inflation-adjusted gains from home sales, and holding periods show a consistent multi-century decline.

After considering housing markets themselves over the centuries, I contextualize housing in the asset universe over time. My new very long-run data adds to emerging evidence that a major turning point in asset markets took place around the year 1650 – an era that saw public assets first assume "safety status", and a time when mortgage interest rates followed trends in sovereign rates and originally assumed their secular downward trend. Both real mortgage and real sovereign rates are trend stationary series showing a steady multi-century decline, with few structural breaks. The idiosyncratic risk of housing assets was highly elevated prior to circa 1650 – but since then, our new data suggests that fire sale frequencies in Germany have been highly comparable to "normal" times in current U.S. housing markets: the average fire sale frequency – replicating definitions introduced for contemporary residential housing markets – at 6-7% over 1650-1910 stands at remarkably close levels to the 1987-2009 average for the U.S. In other words, it was apparently during this crucial single century that the fundamental regularities of modern asset pricing were established, including key modern relative risk and return patterns. The records suggests that the 21st century era of low mortgage rates – a factor often causally linked to the contemporary house price boom – evidently has deep historical origins, and that it was the sovereign sector that has been in the "driving seat" of rising risk premia in the secular context.

Parts 3 will be mainly concerned with the construction of the new multi-century primary source real house price index, as well as return series, with section 4 presenting machine learning reconstructions for full global series, and analyzing "long-cycle" trends. Section 5 focuses on new multi-century total return series for Germany, with Part 6 investigating housing market crashes and fire sale frequencies – as well as the link between income growth and house price growth over time. Afterwards, we will analyze econometric evidence in section 7, before turning to the holistic view of housing and "safe" asset dynamics – investigating the major safe asset inflection around the year 1650 and secular trends in mortgage rates. Part 8 concludes.

2 Literature

The analysis of long-run housing market dynamics has been reinvigorated over recent years, though not only significant empirical drawbacks, but also key controversies remain over both basic trends in real estate itself – as well as its performance relative to other asset classes.

In a comprehensive paper, Knoll et al. (2017) reconstructed house price series for 14 advanced economies over the years 1870-2012, mostly using selected urban price data points for earlier half of their sample. The authors find that real house prices for residential properties in advanced economies were stagnant in the pre-1945 era, and afterwards began a long-run acceleration from the second half of the 20th century. Specifically, the authors concluded that:

- "From the last quarter of the nineteenth to the mid-twentieth century, house prices in most industrial economies were largely constant in real (CPI-deflated) terms. By the 1960s they were, on average, not much higher than they were on the eve of World War I. They have been on a long and pronounced ascent since then, giving rise to a hockey-stick pattern of house prices in the long run."

To reach this proposition, Knoll et al. (2017) undertake a structural break tests for the German and 13 other real house price indices and identify the years around 1964 as the key inflection point from which house prices began their secular acceleration. This German inflection point (1964) is close or even identical to the majority of other advanced economies the authors test.[3]

In a subsequent extension of the work, Jorda et al. (2019) contextualize long-run real estate asset performance in the universe of asset returns and suggested that real total housing returns outperformed equities over the long-run, even when adjusting for the volatility of such returns.

Methodologically, the approach in Knoll et al. (2017) and Jorda et al. (2019) has been challenged by Chambers et al. (2021) on the basis of new U.K. data over 1901-1983, and by Eichholtz et al. (2021) for Dutch and French pre-1943 data. Both studies suggest that once rental income and expenditure components are properly integrated into long-run residential housing return data, housing in fact performed much worse than suggested in Jorda et al. (2019), and in fact fails to outperform equities when adjusted for volatility.

In a recent study, Lyons et al. (2024) reconstruct U.S. house price and total return series over 1890-2006, using a hedonic index approach covering 30 cities on an annual basis using newspaper sources: their data revises several stylized facts in the Case-Shiller index, and proposes that the muted volatility for housing as an asset class suggested by Jorda et al. (2019) could be the result of the aggregation method on the national level: however, the authors also find rather stagnant real house price dynamics prior to the mid-20th century.

As for the drivers of housing boom and bust cycles, there continue to exist alterative emphases, many of which are not mutually exclusive. Demographic factors and personal beliefs, for instance, have recently been invoked (Landvoigt, 2017; Korevaar and Francke, 2024). But a substantial majority of studies acknowledges the role of credit markets, and here especially the credit supply side, prominently (Mian and Sufi, 2009). The fall in U.S. mortgage rates has been identified as a key variable capturing an array of lending constraints, the weakening of which promoted rising credit supply in the wake of the 2008 crisis (Justiniano et al., 2019). The latter in particular contend that:

- "Lending constraints are a simple modeling device to capture a combination of technological, institutional, and behavioral factors that restrain the flow of funds from savers to mortgage borrowers. Starting in the late 1990s, the explosion of securitization and of market-based financial intermediation, together with changes in the regulatory and economic environment,

[3] Eight out of the 14 advanced economy real house price indices record the key structural break between 1952-1964 on their basis; the authors use a standard Bai and Perron (2003) set-up, allowing for up to three breaks.

lowered many of these barriers...the associated shift in credit supply remains the only force pushing interest rates lower."

In this sense, credit supply factors lower the real mortgage interest rate and through additional mortgage lending, real house prices rise. And not least the study of historical housing booms has expanded, where credit factors have also been found to play a decisive role (Rajan and Ramcharan, 2015).

3 Constructing a long-run repeat-sales house price index (RHPI), and real total returns

Our basis for the construction of the new German housing price and total return indices are city level individual property records, known in German as *Häuserbücher* or *Hauschronik*. These are comprehensive compilations of cadaster and other official municipal records that allow a full chronological reconstruction of property level ownership, transactions, repeat sales prices, personal information on the occupants, and (occasionally) rental details. In effect, the data allows a construction of an index methodologically similar to the widely used Case-Shiller repeat sales index for the U.S., which is still regarded as the most robust long-run approach controlling for quality changes and heterogeneous housing characteristics.

Major progress has been made in recent years in the digitization of methodologically sufficient housing records over very long periods of time. German archives have spearheaded some of these initiatives, which – combined with new multi-century granular data for related asset classes – makes this country especially suited for new efforts at a holistic and robust general asset market reconstruction. Figure 1 displays an example, an entry from the new "Topo N" project for the city of Nuremberg (one of the key early modern financial hubs of Europe), which as of 2023 has systematically linked close to 4,000 property level records via unit-identifiers, and merged this cadaster information with ownership histories, sales prices, and other notable events related to the property.[4] Such advancements mirror those in other cities and allow repeat-sales observations for thousands of properties over centuries for consistent individual housing units – for more than a dozen key German cities from the late medieval period.

These new sources have several advantages: perhaps most importantly, their level of detail on the property level allow a full repeat-sales index construction, in line with benchmark contemporary indices: such a methodology is considered the "gold standard" among various alternative approaches, since it allows a better control for quality changes in housing, a distinct concern for real estate as an asset class in existing literature. Second, as these records merge official with notary information, they contain *both* tax assessment values and market values of the property, with the latter being much preferred as a measure of actual price dynamics, though much literature (including the Case-Shiller index) has had to rely on assessment or self-reported values for earlier

[4]See methodological details in Razum et al. (2023).

periods thus far, which contain problematic biases.[5] Third, the records are unusually consistent and complete: the average length for individual properties included in the index that is continuously documented stands at 201.5 years, with a maximum of 407 years, and more than one-third with over 300 years of continuous records. Typically, property related information is quite abundant in this source type, with a significant number of property level records reporting details such as building year of the property, underlying land values, incidences of significant material damages, and quality changes (significant renovations, additions, or mergers with other properties).

Figure 1: Example entry from the 2024 Nuremberg "Häuserbuch", *Unterer Bergauerplatz 10*.



Notes: The picture displays an example entry from the Nuremberg *Häuserbuch* ("Topo N" Project), for the modern address of the *Unterer Bergauerplatz No. 10*. Consistent cadaster units are traced here in their ownership history, sales transactions, sales prices, and other notable events associated with the house. In this case, we see the first ownership entry (category *Besitzer / Bewohner*) for the year 1479. Entry via: https://online-service2.nuernberg.de/stadtarchiv/zeig.FAU?sid=574BA1843dm=6ind=2ipos=4220332f34.

In the construction of the index, I focus solely on actual market transaction prices – ignoring tax assessment values of properties, which are often given, as these are noisy given variation in property tax rates, irregular assessment, and underreporting of actual property values by owners.

For the headline index, and all headline return figures, I arithmetically weight observations across all properties for the headline indices. However, a value-weighted version can also be constructed and is presented in the appendix, which rebalances index weights based on property values every single year (using interpolations for years where individual properties are not on the market).

[5]Not least, non-sales transactions (inheritances, transfers, or property swaps). The Case-Shiller index for U.S. pre-depression home values uses self-reported survey data points via – these drawbacks have been critiqued in White (2009) and elsewhere.

This value-weighted version suggests slower real price growth for higher-value properties over time, and slower real house price growth prior to the Thirty Years War, but otherwise comparable secular trends and inflection points.[6]

[6]See further discussion and data in Appendix section 4 and Figure A.2.

3.1 Summary Statistics

The German residential house sample covers eleven cities, spanning a heterogenous geographical and demographic range in the country over time. Three cities are in Northern Germany, eight in Southern Germany, and the size of cities ranges from 1,300 (Stengberg, as of 1500) to 538,000 (Munich, 1905). All the key financial hubs of Germany/the Holy Roman Empire over the early modern and modern period are part of the sample, including Nuremberg, Frankfurt, Munich, and Berlin. While such ex post successful cities may feature some degree of "superstar city" bias, the inclusion of smaller and relatively stagnant towns balances the aggregate sample regarding these possible factors.[7]

In total, we cover more than 200 individual properties at this point. The properties are exclusively single or multi-family residential objects, typically in the "old" parts of the respective cities. A significant share of the properties in the sample continues to exist as of 2024, based on a cursory survey – even though house numbers and other designations have repeatedly changed.[8]

The houses in our sample have a median value of 594 Rheinflorin (Rfl., or *Rheingulden*) in 1465, a figure that has risen to 2,025 Rfl by the year 1650, 4,537 Rfl. by the year 1750, followed by 18,131 Rfl. by the year 1850, and finally 33,753 Rfl. at the eve of World War One (1910). The small town of Stengberg records the lowest median house prices over the sample period at 224 Rfl., while Berlin records the highest median house price, at 14,392 Rfl.

The 202 properties between them account for 1,475 sales transactions, and together the repeat sales data allows a complete tracing of more than 44,000 property-years, with records starting as early as the 14th century for Nuremberg, Frankfurt, and Erfurt. The final property sale observation in our sample is for the year 1943, in Nuremberg. Of course, a sample of several hundred observations must still be considered "small" by the standards of the German housing stock, even in the early modern period. After all, more than 4,000 individual housing units existed in the early modern city of Nuremberg alone. Yet, our sample is designed to be highly representative of the German residential housing stock given its geographic composition; and even now, with its modest size, this sample presented here represents the most comprehensive one already for repeat sales at the individual property level. Our exercise does not embrace a "big data" approach – but it is easily scalable based on the new sources identified.

Tables 3 and 4 record some of the accompanying data from the Häuserbucher. For instance, we note that the average holding period – defined as the time between actual market sales transactions (thus excluding inheritance events or house swaps) fluctuated between 27-36 years, with a modest declining secular trend. In nominal terms, property owners recorded a gain of almost 94% over the previous sales price, with an upwards secular trend. We will return to such accompanying

[7]"Superstar cities" may exhibit faster house price growth, biasing the index upwards; however, other research suggests rental yields in these cities are generally lower.

[8]House numbers in any case are an innovation of the 18th century. In the pre-1700 era of our sample, the properties are typically designated by their owner, or by lengthy descriptions of their location relative to prominent buildings in the city (the church, city hall, or wells).

data and their interpretation.

3.2 A new repeat-sales house price index

Existing repeat sale indices typically use CPI data to adjust nominal house price series to real bases. Shiller (2015, chapter 3), for one, uses year-to-year U.S. CPI index changes to deflate respective nominal home price changes and create a U.S. "real home price index" over 1890-2014. Similarly, Knoll et al. (2017) deflate nominal house prices with a 5-year lagged realized CPI (that is, the average over t-5 to t-1, to deflate nominal price at t=0), to obtain real house price indices.

Such repeat-sales indices are regarded as "state of the art" indices, and not least they are widely considered the best methodology to control for quality improvements in homes, though alternative "hedonic indices" have been used recently for quality-adjusted U.S. series Lyons et al. (2024). Yet, while they can capture many of the quality-related changes in housing as a wider asset class – for instance, they are by design well equipped to deal with the land component of the home price, as they keep it constant at the property level – even repeat-sales indices are far from *perfectly* stripping out pure quality-related improvements. We note here that we follow existing approaches in incorporating quality-related adjustments to the best extent possible, and dedicate a subsection as well as an extensive chapter in the appendix that traces quality-related changes in our sample, together with better estimates on their effect on secular prices.[9] But importantly, we do by no means not rule out that much or most of the price index changes documented *do* in fact stem from quality-related improvements. The same quality changes are explicitly incorporated into all existing benchmark indices, without a definitive determination on their ultimate role in index changes. Even though, for instance, the long-run suggests that the median homeowner only possesses a 30-50% larger home in terms of living space, it might well be that representative homeowners are more and more willing to pay premia for other quality improvements (over their income growth, as we will see).

Figure 2 now displays our new long-run German house price index (RHPI), here in real terms, over the period 1465-1910. We observe that this index is quite sensitive to the price index basis one uses to adjust nominal house price growth, most strikingly related to the beginning of the Thirty Years War in 1618 when Germany experienced a dramatic inflation event (an issue we return to later).[10]

The two indices are closely tracking each other, however a major difference relates to the treatment of the Thirty Years War, the biggest historical inflation shock next to the German hyperinflation years of the 1920s. The contrast is most acute when we construct long-run real house price or total return indices. Over the full sample 1465-1910 period, the Schmelzing (2025) inflation basis – which constructs a seven-year lagged realized CPI figure that is analogous to the approach in

[9] See Section 3.4 and Appendix section 5.

[10] While the topic has not received much attention in recent evidence, the precise choice of the inflation adjustment basis also makes significant impact on more recent benchmark indices, including the choice whether to adopt a lagged inflation figure (as in Knoll et al. (2017)), or a raw year-on-year one (as in Shiller (2015)).

Knoll et al. (2017) and is concentrated on urban prices – suggests that house prices rose by just 2.1x in real terms; the Pfister (2022) basis on the other hand – which uses a year-on-year industrial and agricultural price index aimed to capture Germany as a whole –, results in much lower inflation spikes of the 1620s, and arrives at a level of 41x.

However, regardless of the inflation basis chosen, a key commonality of both indices displayed is the sharp acceleration of the index values from the late 18th century. In real terms, the index on the Pfister (2022) basis increases by a factor of 2.7 between the end of the Napoleonic Wars and 1910; on the Schmelzing (2025) inflation basis, the index value rises by a factor of 2.2 in real terms over the same period.

This suggests that real house prices – at least in one key geography where such returns can be measured granularly over time – did *not* begin to accelerate only from the mid-20th century, as key literature proposes (Shiller, 2015; Knoll et al., 2017). Instead, such an impression appears to be a function of a limited time horizon considered, one that begins observations in 1890 or 1870 respectively. We visualize this result more strikingly in Figure A.3, which now integrates the new long-run German real house price index with the previous index values in Knoll et al. (2017). This Figure shows more straightforwardly that the house price acceleration well precedes the proposed 20th century inflection. In a subsequent section, we can further test the idea and the timing of particular "inflection points" more systematically, with the help of econometric exercises (section 5).

This key point can be underpinned more robustly via econometric tests: Table 6 in the econometric section of this paper features several reconstructions of long-run real price indices – including crucially one version that now fuses the new pre-1911 German house price data presented in this paper with the post-1911 data previously constructed by Knoll et al. (2017): this fused series running over 1465-2020 for Germany records no single structural break in the conventional Bai-Perron (Bai and Perron, 1998) test setting (the same test used by Knoll et al. (2017), but with extended sample length). This formal result is consistent with recent evidence from sovereign interest rates that also emphasized how sensitive to over-identification of structural breaks shorter sample time series can be (Rogoff and Schmelzing, 2024).[11]

We stress that the new data does not rule out that there has indeed been a transitory slowdown in house price appreciation around the mid-20th century, in Germany and other advanced economies. Plausibly, this could be connected to the well-documented clampdown on the financial sector during the Bretton Woods era, including the subdued growth of mortgage credit.

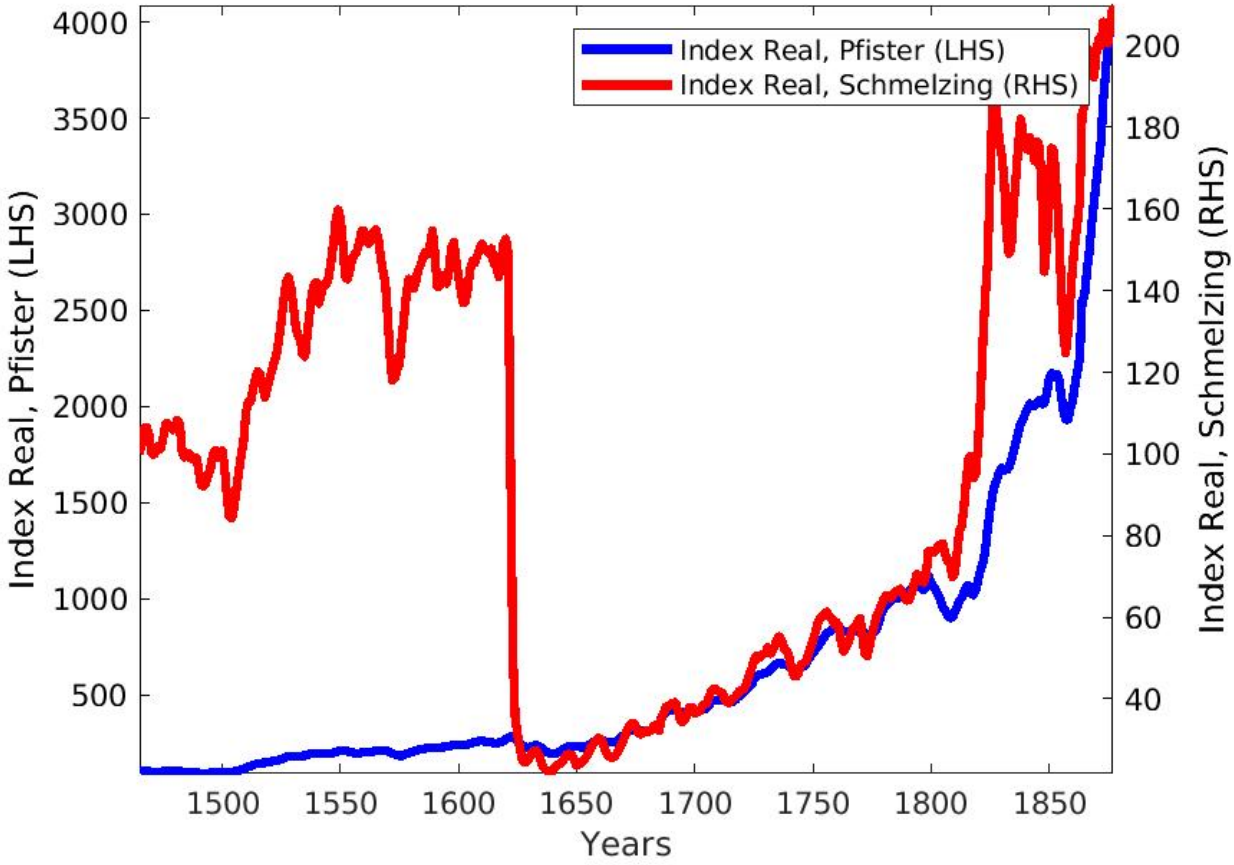
[11]This fused series over 1465-2020 is shown visually in the appendix, via 3.

Table 1: Summary Statistics for Housing Index (RHPI), repeat sales

	# properties	# transactions	Property-years	city size
Erfurt				
1300-1670	5	6	564	med
Stengberg				
1465-1860	17	91	4,240	sma
Mainz				
1604-1808	2	5	140	med
Frankfurt				
1358-1864	27	119	6,280	lar
Koblenz				
1408-1806	18	40	2,742	med
Berlin				
1658-1858	40	281	4,312	lar
Munich				
1391-1904	55	624	15,038	lar
Freiburg				
1572-1904	3	3	55	med
Dessau				
1693-1933	3	9	281	med
Nuremberg				
1387-1943	32	295	10,397	lar
Total				
1300-1943	202	1,473	44,052	—

Notes: The table reports the sample composition of the repeat-sales observations for residential real estate in Germany. Property-years reports the sum of all property level spans of years between first and final sales transaction. City sizes are grouped into three categories: ′"sma" (small cities averaging under 50,000 population across sample period), "med" (medium size cities averaging between 50,000 and 80,000 population across sample period), "lar" (large size cities averaging over 80,000 population across sample period).

Figure 2: German real house price index, 1465-1910. Here 1465=100.



Notes: The plot depicts the German house price index, in real terms. Two bases for the inflation adjustment are presented, one using the lagged inflation series for Germany in Schmelzing (2025, red series), the other using the Pfister (2022, blue series).

3.3 Renting and owner-occupation

According to Dirlmeier (1978), even lower middle and lower income households typically lived in their own single family home by the late 15th century – with around 30% of taxable citizens in German urban areas living in rented houses or apartments. Across the country, this figure appears relatively stable and suitable to assume as an average in the early modern era. For the year 1384, 23% is the equivalent figure for the town of Esslingen. In Rostock as of 1522, 57% of households live in rented real estate. In Nuremberg, the share is estimated at 29% in the year 1502.[12]

Overall, therefore, rental income constituted a clear investment motivation for buyers of real estate assets over the entire observation horizon, and to assess housing as an investment asset, the integration of rental yields is imperative to reach total return figures, and assess actual income risk.

[12]Nuremberg data via Sachs (1915). Other data via Dirlmeier (1978).

Table 2: Summary Statistics for rental yield observations

	# properties	# rental obs	Property-years	av yd
Basel				
1352-1566	5	6	215	7.1
Freiburg				
1407-1564	17	94	4,240	9.1
Konstanz				
1604-1808	2	5	140	6.5
Koblenz				
1624	1	1	1	4.9
Munich				
1401-1529	4	4	65	3.0
Warendorf				
1772-1863	7	100	186	7.9
Nuremberg				
1529-1659	5	6	14	7.2
Bremen				
1650-1765	2,435	2,438	38,960	2.9
Frankfurt				
1378-1902	28	31	37	10.9
Berlin				
1754-2019	>500	29	n/a	4.6
Total				
1352-1863	2,505	2,678	43,845	7.4

Notes: Rental yields are expressed as a percentage of sales price throughout, taking the price observation that is closest to the nominal rent observation in cases where no direct matching is available in the underlying source itself. Bremen data records city-wide averages across all rental properties assessed via Schwarz (1968). Munich also includes Strassburg and Augsburg data; Frankfurt includes Giessen data. Column 5 records the average gross rental yield in the respective sample, in nominal terms, as a percentage of the house market value. The modern Berlin data is based on census statistics via Bundesamt (2023), which does not provide the underlying sample size for the aggregate figures – hence we designated a "n/a" value to column 4 for Berlin.

As has been noted in related papers, historical rental data in primary sources is generally more elusive, hampered in part by the fact that rental contracts were privately negotiated and did not have to be registered with notaries or municipal authorities (unlike sales), in part by a convoluted nomenclature in early modern contracts. Housing contracts – besides mentioning the assessment or sales price – often refer to *Guelten*, or *Zins*. This is especially complicating the construction of price and rental series featuring the *identical* housing properties: key recent literature has navigated this challenge in different ways, with some constructing separate housing and rental series (featuring different properties in each of the two samples) which are then merged to construct a rental yield series (e.g. Lyons et al. (2024)). However, our *Haeuserbuecher* contain a critical amount of detail, at least for multiple key cities, which allows a direct linking of rental and price series – and several hundreds of additional rental-only data points have been identified in related primary and secondary sources which allow the replication of existing approaches that construct a separate rental index series that is subsequently merged with price series to observe rental yields (all rental observations are summarized in Table 2). The level of detail in such rental sources allows the matching of identical property sizes (number of rooms) and within-city location.

4 Long-Run Housing – A Machine-Learning Approach

It has recently been argued that machine learning approaches clearly outperform traditional methods in predictive empirical asset pricing applications (Gu et al., 2020). Our long-run real estate analyses potentially lend themselves extremely well to new machine-learning approaches, given the availability of large sets of (thus far unexploited) known covariates for several key advanced economies over centuries.

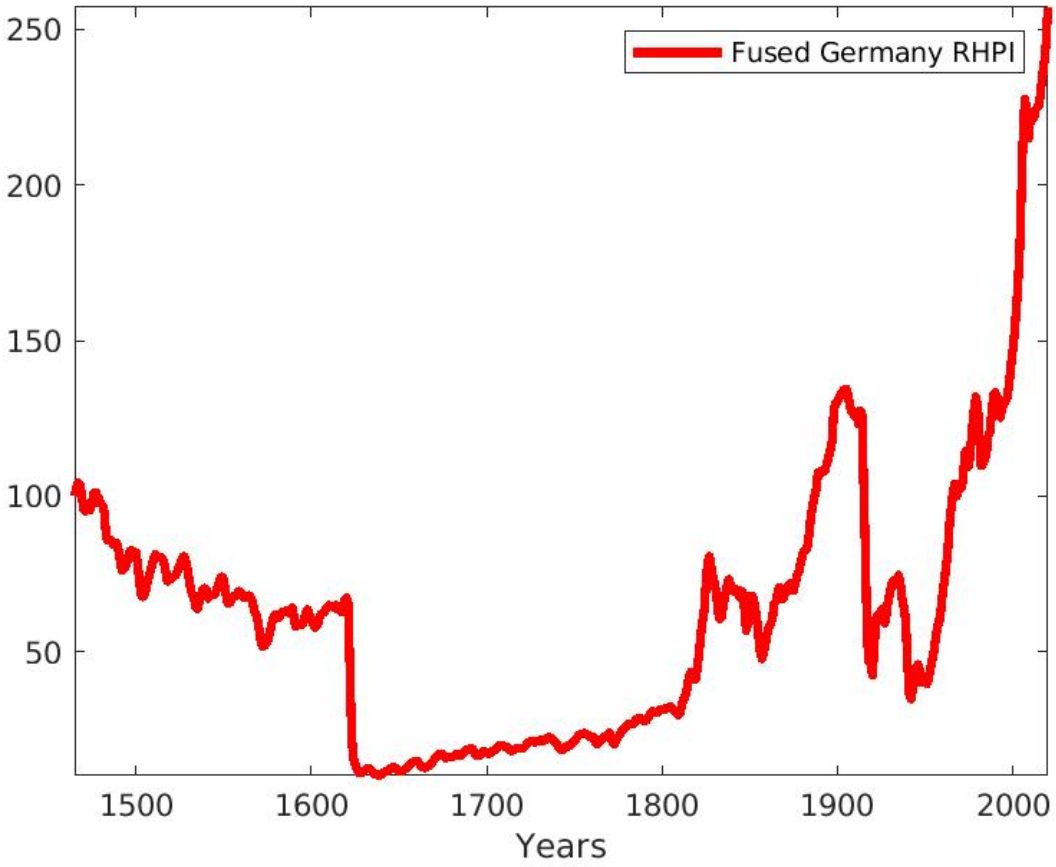
Specifically, we train a machine-learning model on modern nominal housing capital gains as its target variable. A plethora of available models exists – with our focus being on a subset of latest generation models optimized for multi horizon tabular fore- and backcasting applications.

Among the models we test are a Time-series Dense Encoder model (TiDE) (Das et al., 2024); a Seq2Seq+ model (Keneshloo et al., 2020); and a Temporal Fusion Transformer (TFT) model (Lim et al., 2021).

The first step consists of the training stage, to train the machine-learning model, with annual residential house price change (in nominal terms) as its target variable. We train the model on housing capital gains on the basis of the most recent modern and early modern research datasets where a sufficient sample of additional covariates exists. The covariates importance across our specific ML models is detailed further in the appendix.[13] The source of the training dataset (1870-2020) target and covariates values is mostly the "JST dataset" (Jorda et al., 2017) – with the exception of building cost indices which we hand-collect from national statistical agencies, and

[13]See appendix section 6 for all model-specific variable importances. Specifically, the ten covariants include the building cost index change, population growth, 3-year lagged population growth, nominal interest rates, change in nominal interest rates, real interest rates, inflation, 7-year lagged inflation, change in real per capita income.

Figure 3: Fused S-JST real house price index, 1465-2020.



Notes: The Figure displays a German real house price index running over 1465-2020 (1465=100). Here we splice the new data introduced in this paper for 1465-1910 (using the "Schmelzing" inflation adjustment basis), with the existing German house price data in Knoll et al. (2017) over 1911-2020 (as updated in Jorda et al. (2019), and denoted "JST"). The gaps that JST record for selected German years are filled by taking the arithmetic average of the real house price change for Denmark, France, Switzerland, and Belgium.

with the exception of U.S. data for which we utilize the superseding data in Lyons et al. (2024).[14]

Using this set of time series for training, we report the in-sample model training performance in Table 3. We observe that a *Seq2seq+* model with specific tuning parameters performs best and achieves an in-sample R-squared over the full training dataset of 0.496 when optimized for a 36-year forecast horizon, and a 115-year context window.

The TiDe and the TFT models record meaningfully lower R-squared, up to 0.169 – but both are optimizing for MAE performance, where they perform comparatively to Seq2Seq models.

In Figure 4, we display the Seq2Seq machine-learning reconstruction – for four key advanced

[14]It should be noted that while we could potentially broaden the training dataset to encompass further pre-1870 time series featuring the target variable for relevant countries (for instance early Swedish house prices via Carlsson et al. (2022)), across all models the evidence suggests that such a step does not improve training model performance, mainly due to data gaps in the covariates.

Table 3: Machine-learning model performance. Target variable: DM annual house price change

	r-squared	MAE	forecast horizon	context window
Seq2Seq+, 120-32	.331	.032	32	120
Seq2Seq+, exh, 115-36	.496	.033	36	115
Temporal Fusion Transformer (TFT)	.169	.043	36	115
Time Series Dense Encoder (TiDE)	.027	.038	32	110

Notes: The table reports training results from several machine-learning (ML) approaches, all with nominal residential real estate price change as their target variable. The training data set consists of house price changes in addition to ten co-variant variables, annually over 1870-2020, and 1689-1748 (Netherlands).

In the next step, we use the best-performing training model to generate a predictive backcasting house price growth series spanning 1502-1910. This best-performing model is the Seq2Seq model with a forecasting horizon of 32 years. To maximize this optimal forecasting horizon, we generate the target variable on the basis of sequential 32-year horizons.

economies since the early 16th century. All are indexed to 1800=100, and utilize the full set of ten covariates for the 1502-1869 period, to obtain the target value predictions. For these pre-1869 we mainly rely on new published time series in the Maddison database, and financial time series in Rogoff et al. (2024) and Schmelzing (2025). A key exception is that we hand collect and/or reconstruct building cost indices for these key economies, which represents a variable with high variable importance (appendix section 6). For the first time Figure 5 allows an analysis of the "long cycles" in global house prices over centuries, and a contextualization of the early 21st century "boom" period in advanced economies.

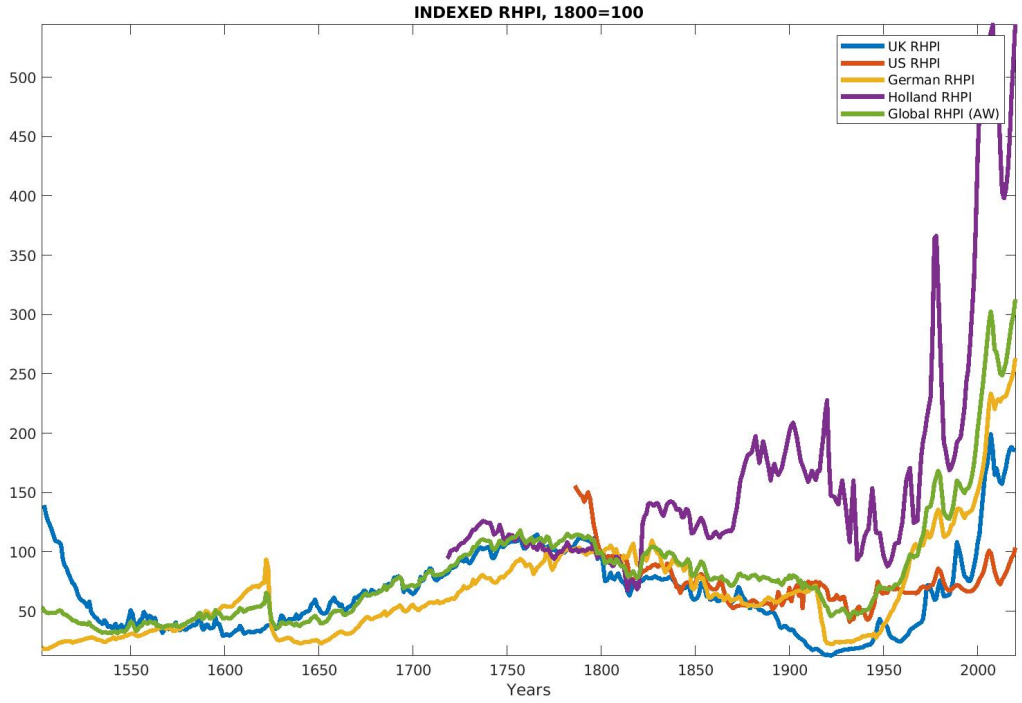
The period of circa 1500-1750 is marked by a significant appreciation of real house prices in advanced economies, with an average global increase per annum of 0.5% (GW) and 0.38% (AW) in real terms – only interrupted by a dramatic fall in prices at the outbreak of the Thirty Years War in Germany (1618). This 250-year house price boom has not thus far been known – and neither the subsequent 180-year long-cycle reversal in global house prices. For in the period of circa 1750-1930, global house prices sharply change direction, and fall back to real price levels that are on some bases lower than in the inception year of 1502. On our basis, global house prices reach at least 300-year lows in the wake of the Great Depression (1932: 109 for GW; 84 for AW).

Following the Great Depression, then, global house prices begin their "contemporary" ascent once more: the rise in both global indices continues virtually uninterrupted, with the sharpest correction in this subperiod clearly being the 2008 housing crisis.

Overall, the Thirty Years War as well as the Great Depression appear to represent the most obvious "narrative" inflection points in real estate over the past half-millennium.[15] Meanwhile, on the "global" levels reconstructed here, the 2008 global housing crises represents one of the most dramatic crashes in real estate since the 16th century (-22.9% peak to trough) – but it is still dwarfed by the most dramatic crash of the full period, the 58% decline of global house prices

[15]For an econometric test of the "inflection points" in both series, see Table 6 below, undertaking a formal Bai-Perron structural break test.

Figure 4: Seq2Seq+ Machine-Learning real house price index (LHS), 4 countries and Global level, 1800=100, 1502-2020.



Notes: The Figure displays real house price indices based on the Seq2Seq machine-learning model, for four advanced economies and the arithmetically-weighted Global level ("Global AW"), all based to 1800=100.

beginning in 1618.

5 Real estate costs, and net and real returns

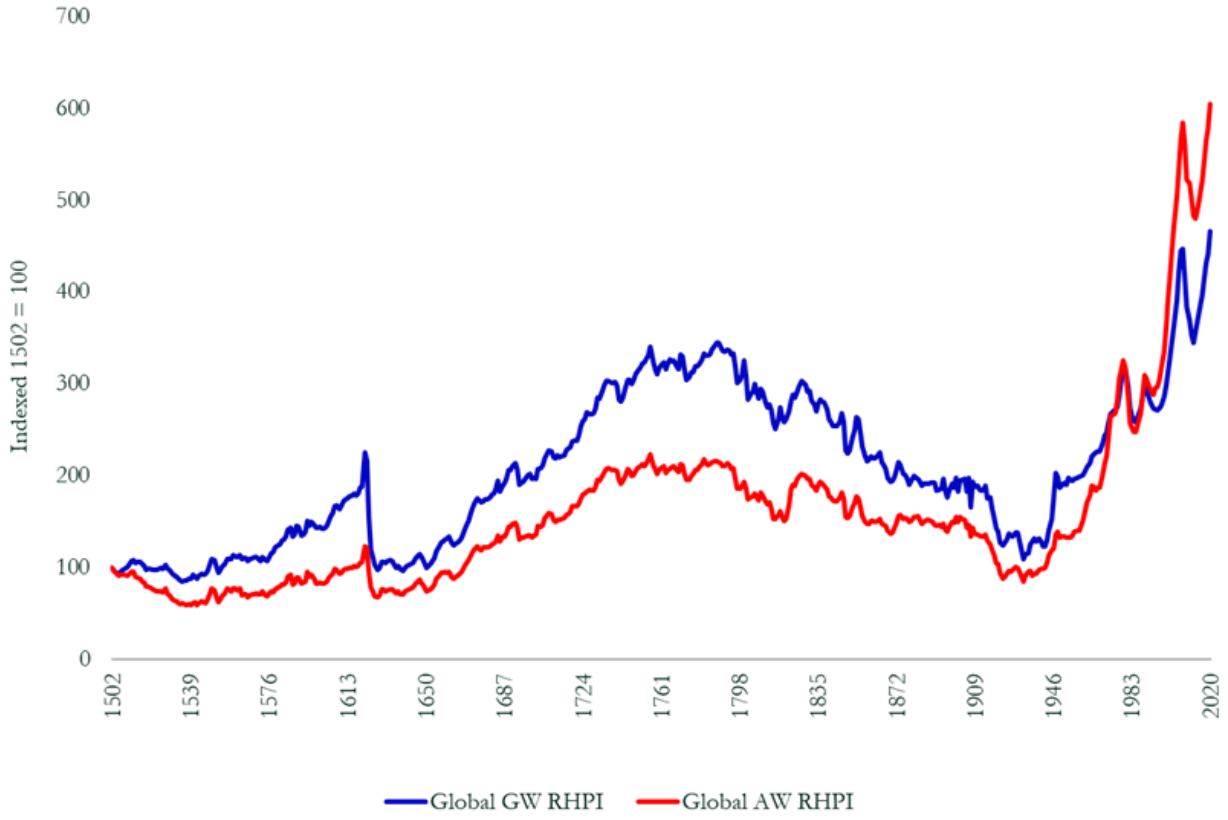
We have not comprehensively measured the cost component of residential real estate for our long-run sample thus far. Such costs mainly include taxes on the municipal and state level, maintenance costs, depreciation, and costs resulting from vacancy.

5.1 Taxes

Beginning with the first dimension, on the property and income tax side, the information is relatively comprehensive. Some of the German *Haueserbuecher* contain occasional unit-level tax information, most of which concur with our existing knowledge of aggregate city level rates.[16] For instance, among larger cities in our sample, we know that for Munich, an annual imposition

[16]For instance, in Nuremberg in 1500, we learn via TOPO N, B 6/5 that the house worth 190 Rfl was taxed at an annual 0.5 Rfl, that is, at 0.3%.

Figure 5: Global Real House Price Index (RHPI), Seq2Seq+ bases, 1502=100.



Notes: The Figure displays Global Real House Price Indices, on the arithmetically-weighted (AW), and GDP-weighted (GW) bases, indexed to 1502=100. Post-1870 values (post-1962 for Germany) are based on "JST" data points for U.K., Netherlands, and Germany – Lyons et al. (2024) for U.S. data points.

of one Penny per Pound is levied from the mid-15th century, where it remains for centuries – a rate equivalent to 0.41% of the (self-assessed) value of the house. The city of Frankfurt charged 5/6 of one percent as real estate sales tax from the year 1613 onwards; the city of Augsburg charged 1/4 of one percent of the value of real estate and land in wealth taxes; the city of Leipzig charged 1 basis point of the (self-assessed) value of housing in irregular wealth tax impositions from 1481 onwards. It is to be stressed that these impositions occurred in irregular intervals – often connected to specific external threats for which cash was quickly needed and liquidity was otherwise constrained.[17]

Afterwards, property tax rates are rather stable from the 15th century, with evidence of a moderate upwards trend. For Berlin, Voigt (1901) reports tax rates of 0.3% of the property value in the 17th and 18th centuries, which rise to 1.25% by the first half of the 19th century. Afterwards, Müller (1881) provides annual rate of 1.9% of the market value for rented residential housing in Berlin during the 1870s and 1880s. With much corresponding data for other cities in our sample in broad agreement, Eberstadt (1903) provides rates for representative Hessian cities, over 1890-1901,

[17]For a systematic overview of tax rates, see Isenmann (2012). The Munich rates are via Solleder (1938, 208ff.). Further city level details in Mayr (1931) for Augsburg; Frankfurt data via Braeuer (1915).

arriving at a lower 0.6% of property value for rental properties.

Against this backdrop, in the subsequent calculations, we operate with a constant 0.15% annual tax rate relative to the market house price prior to 1800, and increase this figure to 0.5% from the year 1800. Slight variations within the range of property rates provided in the literature, or the adoption of a more dynamic rate over time, do not alter any of our basic findings.

5.2 Non-tax costs

What are the resulting time series estimates for long-run total gross costs, as a percentage of value, over our German sample?

It would be methodologically ideal of course to match property level price, vacancy, and rent data with matching property level expenditures – however, such information is sporadic. For some cities in our sample, interesting internal cadaster calculations exist. For instance, the Berlin cadaster authorities during the 1870s apparently calculated with a 2% total gross expenditure figure relative to the current sales value of a rental residential property for total costs, including maintenance, labor, and fire insurance, but not adjusting for vacancy rates (Müller, 1881). A related official publication, also for Berlin, estimates an average vacancy rate for residential housing over the period 1880-1910 of 3% (Ascher, 1917). While providing some general reality checks, however, in line with existing literature, we will have to abstract from property and matched city level data and assume plausible aggregate figures. We will also have to abstract from some relevant city level provisions that are relevant on the margin, but cannot be generalized: for instance, Voigt (1901) reports that for Berlin in the early modern age, renovation costs are partially tax-exempt (up to 15% of total renovation costs) – lacking more specifics about the scope and duration of such provisions, we will disregard such details.

Given the less robust data situation across countries, recent long-run total return calculations thus have assumed time series based on general assumptions, rather than asset-level data. An example is Eichholtz et al. (2021), who estimate non-tax costs of 32% of rental yields as expenditure basis for Paris and Amsterdam, closely in line with the estimates in Chambers et al. (2021), who have actual property level data on expenditures for their U.K. sample. These estimates include maintenance, vacancy, insurance, and labor costs.

The appendix systematically compiles all expenditure share estimates (or actual observations) in secondary and historical literature.[18]

5.3 Total gross returns

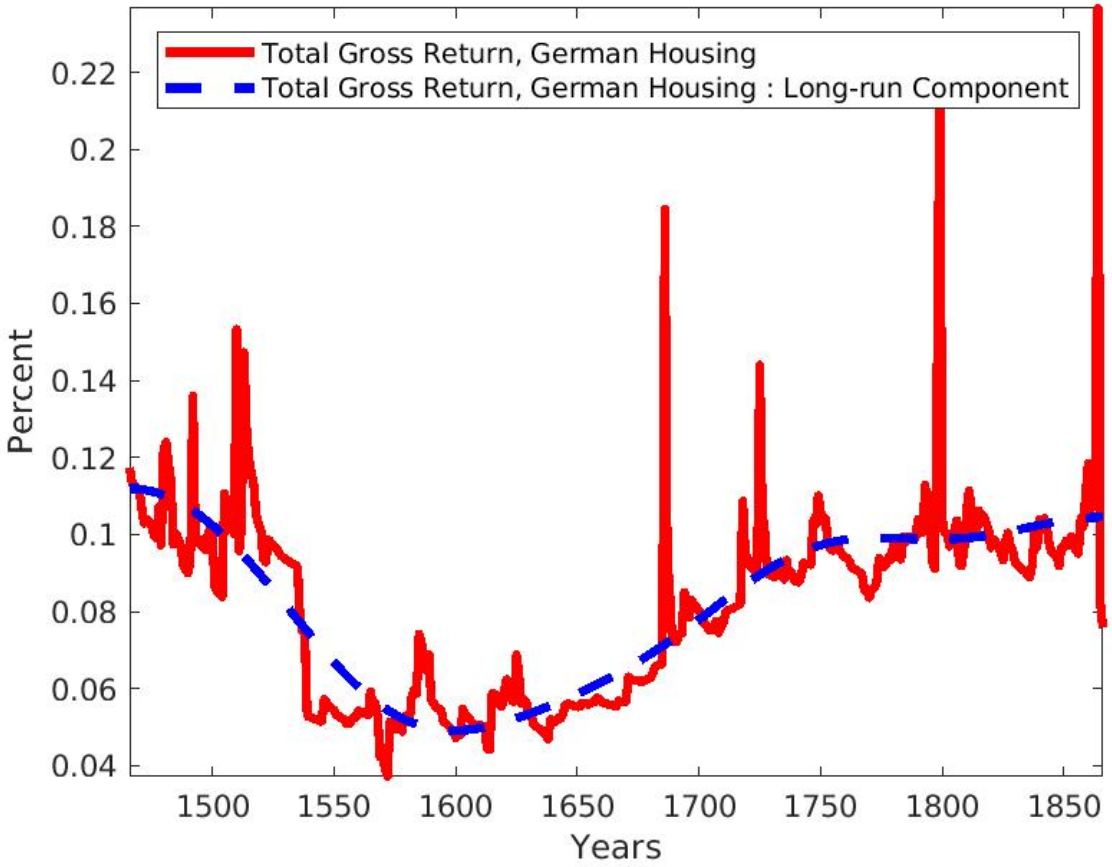
The separate consideration of house price changes, rental yields, and expenditure components now allows the fusion into a total gross return series for German residential real estate since 1466. Figure 6 first displays this time series. What are the main takeaways? We observe that the series

[18] See Appendix Table A.2.

over four centuries displays a "U-shape", initially at levels around 12%, but declining trendwise, and reaching all-time lows around the mid- and late 1500s, at levels just over 4%. From then onwards, total gross returns recover secularly, and return to double-digit levels by the mid-1700s. From then onwards, returns appear quite stable, trending around 10% for the remainder of the sample, despite occasional sharp spikes.

The all-time average nominal total return stands at 5.9% p.a. on our basis, after taxes and all expenditures.

Figure 6: Total Gross Returns, nominal, German housing, 1466-1866.



Notes: The picture displays the housing total return series, in nominal terms. Pre-expenditures, pre-taxes. The blue line displays the long-run trend component following the methodology of Müller and Watson (2018).

5.4 Real returns

We can use either of the two German inflation bases to calculate real total returns on housing, essentially replicating existing return formulas. When using Pfister (2022), we arrive at an all-time (1466-1877) average of 5.2% real residential housing returns p.a. Since the disaster of the Thirty Years' War, this real return appears to trend upwards: just considering the sub-period of 1700-1877, the average real return stands at 6.0%. The Figures are very similar when considering our

alternative inflation basis.[19] Visualized in Figure 7, we observe that the basic "U-shape" revealed for nominal total returns, with a bottom in the early and mid-17th century, is also apparent on this inflation adjusted basis.

In any case, what is clear is that these figures are remarkably close to modern day estimates of residential real estate returns. For instance Ilmanen (2022) calculates a real total return for U.S. housing over the period 1960-2020 of 6.1% real p.a.

Per Himmelberg et al. (2005), the post-1995 U.S. housing market featured a remarkable real house price growth, with average annual real price growth rates of 3.6%. This is consensually seen as an unusually sharp acceleration from the pre-1995 average, at 0.5% real U.S. house price growth over 1975-1995.

How do such ranges compare over the very long run, however? Are they closer to the 1970-1995 period, or the 2000s boom? In fact, on our basis, the average real price growth rate over the full sample 1465-1910 stands at 0.9% p.a. Secularly, this figure sharply accelerates: over 1725-1910, the figure stands at 1.2% p.a.; and over 1820-1910 stands at 1.7% p.a. It appears that secular price trends are actually far closer to the 2000s U.S. boom era than to the 1975-1995 average – it may have been the latter period that constitutes a long-run outlier.

Knoll et al. (2017) propose that real German house price growth underperformed real p.c. GDP growth prior to World War II. Only afterwards, from the 1960s, did real house price growth surpass real income growth rates. Specifically, the authors record a pre-1945 real house price growth rate of 2.1% p.a., using a CPI-adjustment to annual nominal house price index changes. Our new long-run data questions such propositions, and on the basis of improved (especially pre-1945) data in fact reveals the opposite picture.

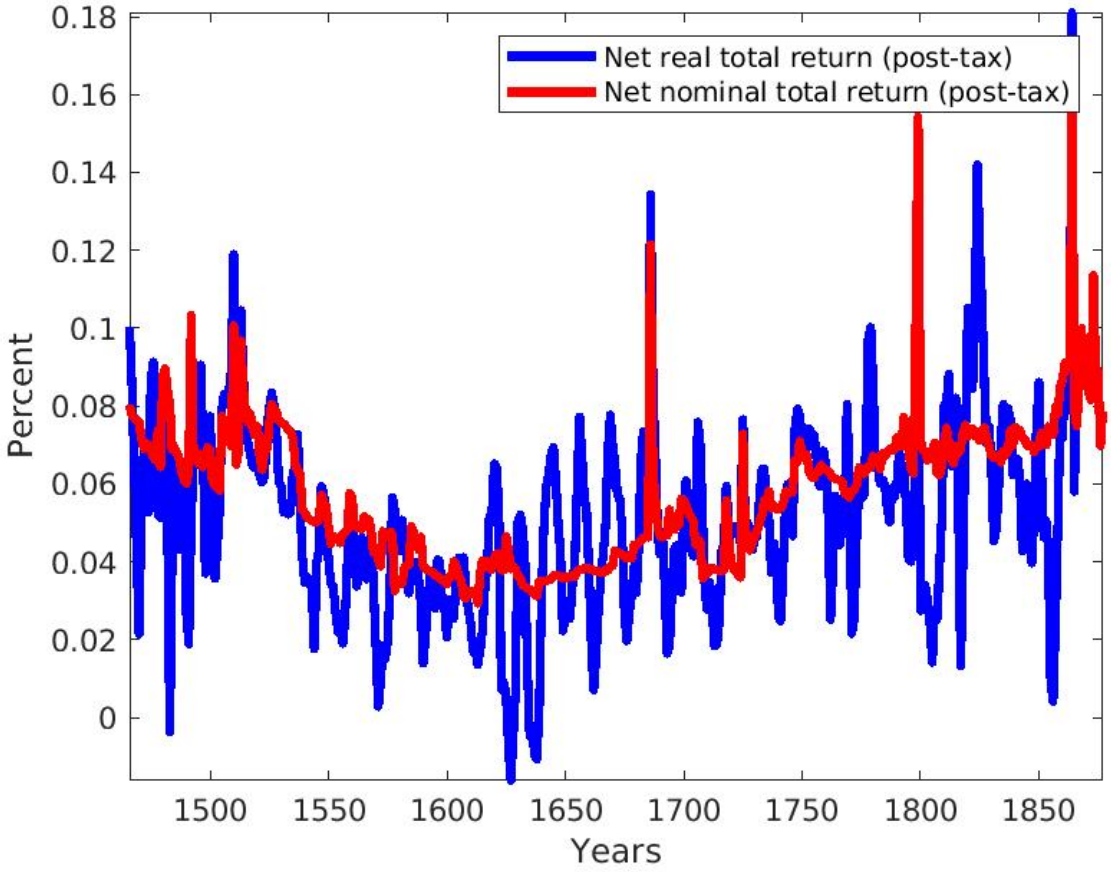
6 Fire sales and housing market crashes

One crucial application of the new housing transaction data is to investigate the frequency and timing of "housing crashes" over centuries. As we observe the realized sales price, we can comprehensively study the occurrence of aggregate housing "crashes" as defined by modern literature, and investigate the context of such long-run evidence.

In addition, the sample allows the identification of "fire sales" that are not related to general market conditions – in other words, idiosyncratic heavy discounting of housing objects against the backdrop of non-distressed aggregate housing markets.

[19] On the Schmelzing (2025) inflation basis, the Figure for 1700-1877 stands at 6.2%, and all-time (1465-1877) stands at 4.6%.

Figure 7: Total Gross Returns, real, German housing, 1466-1910.



Notes: The picture displays the housing total return series, in both nominal (red) and real (blue) terms, post-tax. For the real basis, we here use the Schmelzing (2025) seven-year lagged inflation series for Germany.

6.1 Price gains, holding periods, and fire sales frequency

Table 3 displays summary statistics on the transaction dimension for overall repeat sales, average and median sales price changes (relative to the previous sales price for identical properties), and the average holding period of houses spanning individual (open market) sales transactions.

We observe that the average and median sales price gains (in nominal terms) are strongly positive. Across the entire sample, over 1300-1933, a median nominal price gain of 33.3% is observed. This median is relatively stable over sub-periods, ranging from 33-37%. In average terms, there appears to be an increase in prices, from levels in the mid-80% range, to levels above 100% in the post-1800 subsample. That is, home sales have on average doubled over their previous purchase price in nominal terms from the 19th century onwards.

Broadly the same picture emerges when we measure such sales gains in real terms. On such a basis, all-time median (1300-1943) stands at 13.5%, with a secular upwards trend reaching a

sub-period record of 20.6% over 1800-1943.[20]

At the same time, holding periods appear to have seen a slight decline over time – while the 16th, 17th, and 18th centuries saw average holding periods above 35 years, this figure dropped to around 27 years by the 19th century. This process could be related to improved liquidity, or trends in migration patterns, or other demographic factors. Much modern data is not directly comparable to such statistics, but those that are indicate that as of the 21st century, typical holding periods in real estate have declined further.[21] In any case, this apparent (moderate) downward trend in holding periods mirrors evidence from other asset classes, including the secular downward trend in average effective sovereign debt maturities.[22]

6.2 Fire sales

Recent literature has engaged with these two "crash" dimensions, on the market and individual housing level, and suggested stylized facts. For instance, recently in a study focusing on the U.S. market over 1987-2009, Campbell et al. (2011) have suggested that "forced sales" of housing – including foreclosures – come with an average -26% price discount compared to "non-forced" transactions.[23] However, for long-run historical series, similar definitions are not extant thus far.

We build off this literature and measure aggregate and individual housing distress over the German sample. We take existing numbers as a benchmark for the definition of "fire sales" in German housing over the centuries. For individual transactions, we first start by measuring frequencies where the sales price is at least 25% below the previous sales price in nominal terms.

The advantage of our underlying *Häuserbücher* as sources is that typically, foreclosure events are explicitly mentioned, therefore providing a cross-check that indeed, our threshold is capturing actual distress situations by the sellers.

On this first fire sale definition (-25% and more discount to previous sales price), however, we appear to observe more variation over time. Out of a total of 1,468 transactions, the full-sample frequency of fire sales stands at 7.6%.

Figure 8 displays the long-run trend visually, and reveals several distinct rapid spikes in this distress variable. In particular, the two greatest surges in fire sales appear to have been recorded,

[20] For details see the appendix, Appendix Table A.3.

[21] Neither current official German data or U.S. census statistics are directly comparable given that transfers, sales, and non-sale transactions are not distinguished in aggregate holding period statistics. For modern U.S. commercial real estate, Sagi (2021) records 8.2 years of holding periods on an identical methodological basis as ours. Private data from the provider ATTOM (2024) for the U.S. allow a closer comparison for residential real estate, suggesting that comparable U.S. holding periods as of 2024 stand at 7.8 years, again with a slight secular trend over the past 20 years.

[22] For secular trends in average maturities of sovereign debt assets, see Schmelzing (2025).

[23] The authors focus on residential single- and multi-family home transactions in Massachusetts. "Distress sales" are classified here in two main categories, encompass (a) a sudden death of the owner triggering a sale; (b) a formal foreclosure event. In our historical sample, the focus is on category (b), though in practice the explicitly recorded (b) events include (a) events as a trigger.

first, during between 1495-1505 – when fire sale frequency jumps to an all-time record of just under 30%; and second, during the 1640s, just following the formal conclusion of the Thirty Years War, with an all-time peak of 32.9% over 1648-9: the war period of 1618-1648 itself saw a severe intensification of material destruction in German cities – and it appears that in line with evidence from sovereign debt markets, the recognition of formal default events only got underway when hostilities ended. Consistent with our severe drop after 1618 in the RHPI (-83.9% peak-to-trough),[24] the Thirty Years War in general appears to constitute the most intense real estate market correction ever recorded – it certainly outranks the 2008 crash both in terms of peak to trough real price correction, as well as in fire sale frequency using modern definitions: on the Shiller (2015) basis, 2008-9 saw a 38.9% real house price drop in U.S. data; and per Campbell et al. (2011), the 2008-9 housing bust saw a peak in fire sale frequencies (for MA) at 28.5%.

In this sense, it appears that major geopolitical shocks constituted one of the biggest property-level risk factor in the early modern period, but only to the extent that they were associated with severe material damage – consistent with recent granular material damage statistics (Zwierlein, 2021), war events over 1648-1910 were no less damaging in terms of human costs, but far less so in terms of raw physical (and housing) damage.[25]

In this sense, the 1648 surge in itself marks an epochal asset market inflection point. The most important item in the capital stock over time – real estate – assumed its contemporary, modern "risk profile" after the Westphalian Peace. For if we take the 1650-1910 average in fire sale frequency – recorded at 6.9% p.a. – this average comes extremely close to "normal" levels in U.S. residential housing markets over the full sample period reconstructed by Campbell et al. (2011) for Massachusetts housing markets, for which they record 7.1% along the same definitions.

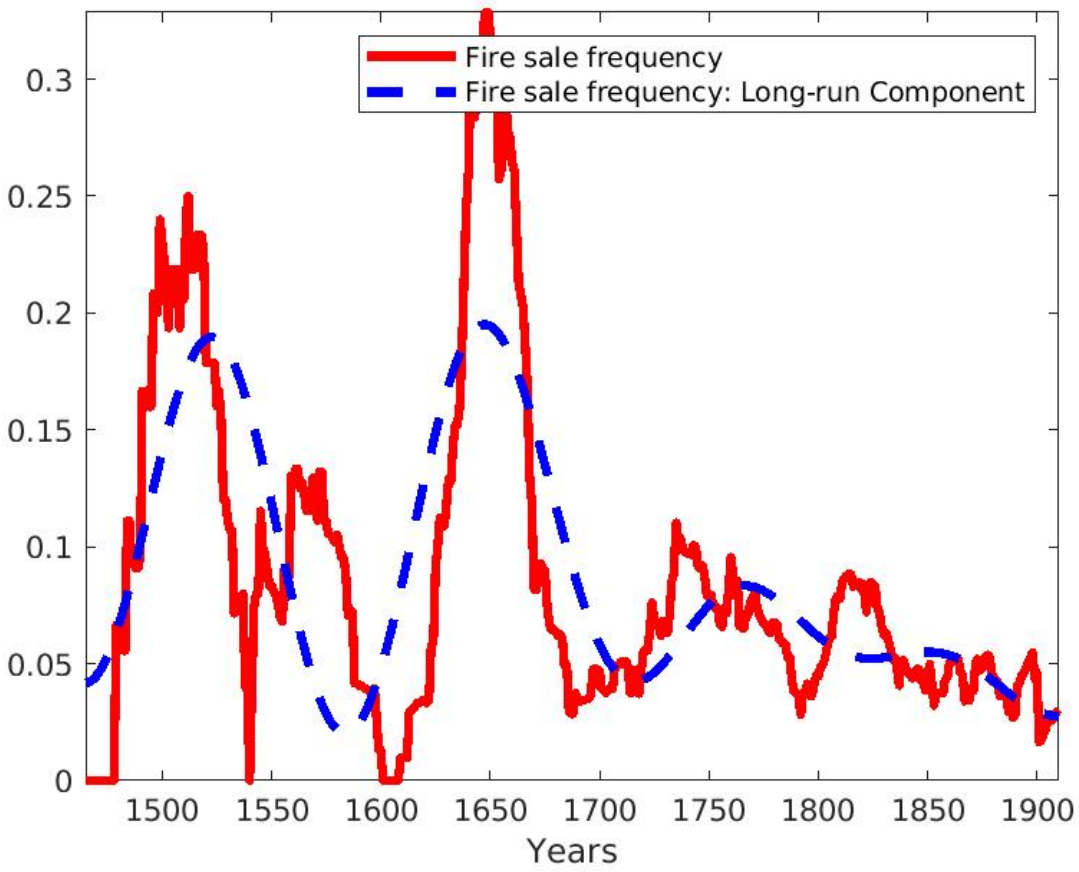
Overall, therefore, the fire sale data over time is a key reflection of the idiosyncratic risk of residential real estate as an asset class. It has long been recognized that this idiosyncratic risk for housing as an asset class is higher than for other asset classes, including sovereign bonds or equities – with housing risk much more difficult to diversify (Piazzesi and Schneider, 2016). In a relative sense, it might still be true that such risks are higher than other asset classes even centuries ago – however, the remarkable fact from our data appears to be that outside of war events, idiosyncratic risk within housing as an asset class – as measured by adopting modern fire sale definitions (Campbell et al., 2011) to German data – by the late 17th century dropped to levels directly comparable to recent U.S. housing data from the 1980s. Idiosyncratic housing market risk appears to have changed very little over the past three and a half centuries. This insight raises fundamental questions about *relative* financial risks of course, and the associated pricing of such risk (risk premia), a question we will analyze in sections 6.2 and 7.

Secularly, it appears that at least over the period of 1466-1910, the fire sales frequency is trending

[24]This figure takes the Schmelzing (2025) lagged inflation adjustment, as per our earlier discussion: the peak in real house prices is recorded in 1620 (167 with 1465=100), the bottom in 1627 (26.9).

[25]Meanwhile, the causes of the 1490s and 1740s surges are not immediately apparent: for the former, fire sales are especially concentrated in the cities of Nuremberg and Stengberg, and the regional "War of the Succession of Landshut" (1503-5) may have played a role; in the latter episode, Munich and Berlin show particularly sharp increases.

Figure 8: German housing fire sale frequency, 1465-1910.



Notes: The plot depicts the rolling share of housing transactions in our sample that record at least a -25% nominal sales price discount relative to the most recent previous sales price. We use a rolling 28-year centered window. The blue line depicts the long-run component of the series using the methodology of Müller and Watson (2018).

downwards. But importantly, however, over the period of 1700-1910, the fire sale frequency, at 5.4% is already highly comparable to the fire sale frequency that Campbell et al. (2011) calculated for U.S. homes over 1987-2009, at 6.1%. Second, the *peak* fire sales frequencies that we observe in the very long-run sample are also intriguingly close to the 2009 fire sale peak as recorded by Campbell et al. (2011) – who record a peak of 28.5% fire sales by 2Q:2009 in their sample.

In general, the fire sale evidence indicates a secularly falling tail risk of housing as an asset class, and ought to result in falling risk premia, all else equal. However, that fire sale risk appears to have levelled off around the year 1700, when frequencies are for the first time closely comparable to some existing modern estimates on comparable measures. Importantly, the well known destruction events of World War I and II are not included in the sample, however – with existing literature excluding such events from 20th century return and index chronologies.[26]

But this fact does not yet tell us much about the idiosyncratic risks. Given that the fire sales spikes

[26]Including Knoll et al. (2017) and Jorda et al. (2019).

Table 3: Repeat sale housing transactions, prices, and holding periods				
	# of transactions	avg. price %	median price %	Avg holding period
Total				
1300-1943	1,468	105.4	32.9	32.7
1500-1850	1,192	106.7	31.1	34.5
1700-1850	792	101.0	30.7	34.6
1800-1943	595	102.1	34.9	26.9

Notes: The table reports summary statistics for market sales transactions of houses in the sample. Average and median price columns record price increase (decrease) relative to most recent previous recorded sales price, in nominal terms. Average holding period in years.

Table 4: Sales at loss and fire sales			
	Share sale at loss	Share fire sales nom.	Share fire sales real
Total			
1300-1943	20.7	7.6	25.3
1500-1850	25.2	8.9	27.3
1700-1850	24.5	7.2	23.6
1800-1943	16.3	6.4	17.9

Notes: The table reports summary statistics for housing sales at losses, including two "fire sale" definitions. All columns refer to transaction values in nominal values, spanning the entire transaction sample summarized in Table 3.

are linked narratively to broad macro shocks, they could simply represent spillover effects from such general crises. Typically, to assess the housing-specific risk, previous literature considered the idiosyncratic risk – the risk of a sharp price drawdown on the individual housing unit level, in "normal times", when general index values are stable or increase.

The bottom line appears to be that idiosyncratic risk for housing sharply declined some time around the mid-17th century, after the largest single destruction event of the Thirty Years War. Fire sale risk became closely comparable to 21st century levels some time around the year 1700.

6.3 Income

The new long-run series enable us to test several canonical hypotheses for housing as an asset class, especially in its long-run context. Paradigmatically, Shiller (2015) in his investigation of U.S. housing over 1890-2015 declared that

- "Reflections from casual observation ought to convince us that homes have not appreciated significantly over the decades...real home price growth must have been less than real per capita disposable income growth, which was 2.0% a year from 1929 to 2013. The bottom line appears to be that, while there is some uncertainty about the actual path of home prices, most of the evidence points to disappointingly low average rates of real appreciation of most

homes...Actually, the theoretical argument that home prices can be expected to appreciate faster than consumer prices in general is not strong."

These suggestions echo the claims in Knoll et al. (2017), that advanced economy home prices have been more or less "stagnant" prior to the mid-20th century. Though some questions over such statements are already implicit in the previously shown Figures, we can test this hypothesis now more systematically over much longer periods of time than previously attempted, and with a closely comparable methodology to the Shiller (2015) benchmark repeat-sales city approach.

Our data allows a granular long-run test of this and related hypotheses. Figure 9 reports summary statistics for German real house price growth on the one hand, and real per capita GDP growth on the other.[27] Three eras are compared separately: 1666-1910, 1963-2020, and 1998-2024. These eras are delineated by key narrative claims, and our new econometric evidence. We observe that between the "most recent" structural break in our new housing series (1666) and the end of the sample in the 20th century, house price growth was consistently higher than real per capita income growth. Next, the era of 1963-2020 is shown in isolation – this is the era reconstructed in "JST" without gaps and the basis for some of their key stylized facts for Germany and beyond. Here, in fact, we do observe that on average, income growth does outstrip real house price growth, by close to 0.6% p.a. But how representative is this specific sample? The third, right-hand panel now displays separately the period 1998-2024, with Shiller (2015) identifying 1998 as the inception point for the U.S. housing "boom market". Over the past three decades, once more, German real house prices have outstripped real per capita income growth.

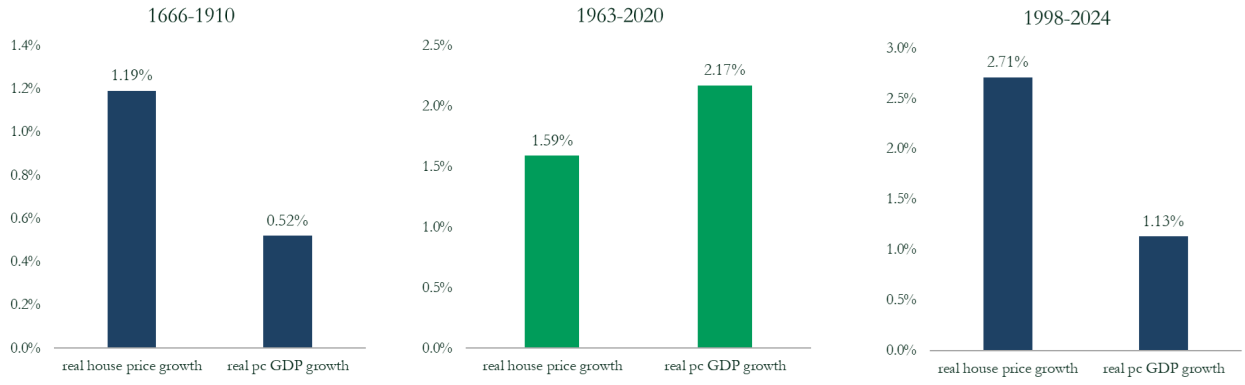
On its own, the persistence over the past thirty years of house price growth in Germany (as in the U.S.) outpacing real income growth may raise doubts to regard it as an "aberration". But an alternative narrative on the basis of long-run patterns could be to regard the late 1990s as the point when the relationship between income growth and house price growth reverted to its "normal" state.

Formally, the income growth basis includes rural German areas, whereas the house price index focuses on urban data. Yet, the difference in the two measures is quite pronounced, and we recall that the house price index not least encompasses smaller rural towns. Overall, we clearly observe that historically, real income growth was consistently outpaced by real house price appreciation: in fact, the opposite appears to be true, with real house price growth on average being three times as fast as real per capita income growth over the period 1501-1910. Interestingly, with housing constituting the leading component of household wealth, this observation would suggest that wealth inequalities should have secularly risen prior to World War One – and that only "recently", with the breakdown of early modern institutions in 1914, such trends reversed. Indeed, this picture is confirmed by new long-run studies on top wealth shares, for Germany but also beyond: indeed, wealth shares rose between circa 1450 and 1914; they dipped over the course of ca. 1914-1970, and

[27] Real p.c. GDP growth figures are via the new time series in Pfister (2022), which begin in 1500 and refer to a comparable geographical basis (e.g. approximating modern German borders excluding East Prussia, Austrian and Bohemian lands).

subsequently started to grow again – a general contour entirely plausible against our housing evidence (Alfani et al., 2022).

Figure 9: Real house price growth and real p.c. GDP growth p.a., three eras in Germany, 1666-2024.



Notes: The plot compares German real house price growth p.a. to German real per capita GDP growth. Pre-1910 real p.c. GDP growth for Germany is via Pfister (2022). The middle panel reports values over 1963-2020 per "JST". The right most panel just reports averages for 1998-2024 extending JST over 2021-4 with Bolt and van Zanden (2024).

7 Econometrics: regressions and structural breaks

We turn to an investigation of the drivers of housing total gross returns, as constructed through our methodology described in previous sections. In general terms, we should expect both supply (credit supply, technological advances, reduction of red tape) and demand (demographics) factors to influence secular trends, and the data availability allows testing both channels for Germany.[28]

Table 5 presents a simple OLS regression with housing gross total returns as the dependent variable. Independent variables include real GDP growth, population growth, the inflation rate, and German real and nominal sovereign long-maturity interest rates.[29] We observe in the regression that PUBPRI and population growth rate both correlate significantly with total gross returns. Inflation rates, real GDP growth (aggregate or per capita) and real interest rates are never significant.

It appears therefore that both supply and demand side factors may play a determining role in long-run housing total return dynamics. Higher population growth spurred demand for additional housing, and the rebound in population growth (in Germany and other advanced economies) from the late 17th century thus provides a plausible backdrop to the supra-secular housing boom.

On the supply side, the finding of significance for real sovereign interest rates is intriguing. This confirmation of credit availability seems to underpin literature emphasizing the role of credit for the

[28]On the "regulatory" side, we note for one that some early modern cities required the approval of the city council if a non-citizen wished to purchase property within their walls. On long-run rent controls, a useful survey is Kholodilin (2024).

[29]GDP growth and population growth data is via Pfister (2022). All financial variables are via Schmelzing (2025).

Table 5: OLS Regression, log excess housing returns (er)

	log er	log er	log er	log er
German inflation	-0.0992	-0.0992	-0.0714	-0.0714
	(-1.36)	(-1.36)	(-1.25)	(-1.25)
Real aggregate GDP growth	0.0307		-0.00961	
	(0.62)		(-0.25)	
Real per capita GDP growth		0.0315		-0.00903
		(0.64)		(-0.23)
Population growth	1.216***	1.247***	0.981***	0.971***
	(7.38)	(7.87)	(7.55)	(7.74)
German real rates	-0.144***	-0.144***	-0.0895***	-0.0896***
	(-5.38)	(-5.38)	(-4.20)	(-4.20)
PUB-PRI spread	-0.0632	-0.0632	0.0198	0.0198
	(-1.58)	(-1.58)	(0.62)	(0.62)
year			0.000138***	0.000138***
			(14.86)	(14.85)
constant	0.000791	0.000788	-0.236***	-0.236***
	(-0.42)	(-0.42)	(-14.84)	(-14.84)
observations	355	355	355	355
Adj. R-squared	0.197	0.197	0.507	0.507

Notes: t statistics in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Columns 1 and 2 are not controlling for a year trend, while Columns 3 and 4 do. Real total gross return is not included as a variable given that it is mechanical. Columns 1 and 3 use German real aggregate GDP growth and Columns 2 and 4 use German real per capita GDP growth, as both measures are highly correlated and therefore cause multicollinearity issues. "PUB-PRI" spread here uses German mortgage rates for PRI basis. All data for the period 1466-1910.

2000s U.S. housing boom (Justiniano et al., 2019), as well as contributions that emphasized credit availability as a driver of other historical housing price boom episodes (Rajan and Ramcharan, 2015).

Overall, we note that the r-square obtained when including all regressors (columns 4 and 5) is quite high relative to existing standards for comparable analyses.[30] In addition, we present a number of variations of this regression in the Appendix, to test the strength of these results – the main result is that population and real rates remain significant, including for a setup that uses gross total returns instead of log excess returns as the independent variable.[31]

7.1 Bai-Perron

Next, we test the long-run series via the standard structural break test of Bai and Perron (1998). The Bai-Perron methodology tests time series for up to five structural breaks, and has in particular been used to identify "turning points" in the canonical housing literature. Specifically, Knoll et al. (2017) use Bai and Perron (1998) as their basis to suggest the 1960s as the inflection point in advanced economy.

The test is however sensitive to the sample length used, and meaningfully improved sample length in particular have been shown to revise canonical structural break narratives in recent macro-finance literature (Rogoff et al., 2024).

We report the results from our long-run series in Table 6. We test both nominal return series introduced in section 5 (gross and net bases), as well as the benchmark real housing price index. For the former pair, we observe that several breaks are revealed: in particular, both gross and net returns share the years 1537 and 1640 as break dates. The gross return series shows an additional break for the year 1742.

Meanwhile, the real price index records no breaks for the full sample length – in particular no break in the 20th century is revealed.

These results specifically put doubts on the idea that a relevant housing inflection point occurred in the 20th century post-war era, as suggested by Knoll et al. (2017). The more likely explanation is that housing market dynamics are characterized by a significant degree of long-run continuity: the acceleration in housing returns, and real housing prices constitutes a truly secular phenomenon that echoes dynamics in other asset classes, including real interest rates – for which new long-run series recently revealed that 20th century breaks disappear when longer sample lengths are considered (Rogoff et al., 2024).

[30] For instance, the classic Mankiw and Weil (1989), in their most encompassing regression for U.S. real excess housing returns over 1947-1985 obtain an r-squared of 0.32.

[31] See Appendix Section 5, and Table A.5.

7.2 The 17th century safe asset inflection

The structural break evidence from housing over the very long run raises intriguing long-run questions, regarding both asset pricing and also political-economic ones. Importantly, the idea of a small handful of structural breaks over centuries – breaks that are concentrated over the era of ca. 1550-1650 – accumulates from new research across different asset classes.

As we saw, breaks in our new real total gross and net returns for housing are clustered over 1537-1640; in addition, mortgage rates inflect over 1666-1685 (Table 6).

Meanwhile, Rogoff et al. (2024) showed recently that long-maturity sovereign real interest rates inflect in the year 1557.[32] This inflection appears to be common to all advanced economy sovereigns, and also plausible constructions of "global" real interest rates. These sovereign real rate breaks in the 16th and 17th centuries are far more consistent and statistically significant than "recent" break dates including 1914 and the 1980s. Finally, "r-g" series which approximate public debt sustainability trends show a cluster of structural breaks in the period 1550-1630, too – across several advanced economies (Rogoff and Schmelzing, 2024).

Considering these structural break exercises holistically, our evidence from the housing market over the very long-run, we first observe that through this lens further evidence accumulates that a major inflection point in asset markets took place in the 100 years spanning circa 1550-1650. And also, it appears that this inflection point is primarily driven by the emergence of the public sector as a "safe" investment asset. Lending to government, in other words, first emerged as a "safe asset" for representative investors.

7.3 Stationarity and forecastability

In their seminal paper, Case and Shiller (1989) analyzed U.S. city-level real house price index changes and excess returns, and rejected random walks in both variables. Subsequent work, e.g. Mankiw and Weil (1989), generally confirmed this observation in U.S. post-war data. In general, we also confirm this finding, for both excess returns and also real house price index changes, with clear stationarity being confirmed when using the conventional ADF-GLS test via Elliott et al. (1996).

We test stationarity also on the city level – where trend stationarity also holds, though with weaker significance. It has long been posited that national house price indices that fuse city level observations by design mask the house price volatility on the city level: indeed, the average individual city level real y-o-y price volatility, at 2.8%, is higher than the aggregate index volatility, at 2.1%. The appendix contains full tables and results, using different set-ups of the test.[33]

[32] This 1557 date was the result of a Chow test, which tests the significance of specific imputed break dates, unlike the open-ended Bai-Perron.

[33] See Tables A.7-A.9, along with appendix sections 6.2 and 6.3.

Table 6: Structural break tests, Bai-Perron basis

	no of breaks	break years
Primary source series, Germany		
Real gross return yoy	3	1537, 1640, 1742
Real net return yoy	2	1537, 1640
Real price index change (AW)	0	–
Real price index change (VW)	3	1518, 1573, 1878
Real price index, 1465-2020, fused S-JST	0	–
Mortgage rates, nominal	1	1685
Mortgage rates, real	2	1666 1799
Machine-Learning series		
Global GW RHPI	0	–
Global AW RHPI	0	–
U.K. RHPI	3	1713, 1882, 1966
U.S. RHPI	0	–
Netherlands RHPI	3	1768, 1921, 1975
Germany RHPI	0	–

Notes: The table reports the results of the sequential Bai and Perron's test (Bai and Perron, 1998). The test is implemented in Matlab using the Matlab function "pbreak" from Pierre Perron's website. The test is applied to the linearly detrended rate series using a trimming parameter of 5 percent and a heteroskedasticity and autocorrelation consistent variance estimator. The significance level is 5 percent, and the maximum number of allowed break points is 5 for all series. When the test rejects the hypothesis of no breaks, the estimated number of breaks and the break dates are reported in the second and third columns, respectively. "AW" denotes the arithmetically weighted index basis, "VW" the value-weighted basis. The series "Real price index, 1465-2020, fused S-JST" spliced the newly introduced German series from this paper over 1465-1910 with the JST data series for Germany over 1911-2020: see Figure 3 above and Figure notes.

7.4 The secular housing boom and credit supply

The regression results in Table 5 motivate a closer look at a key underlying financial variable in this section: private credit through the ages, in particular mortgage rates. This factor is of course of key contemporary relevance given the discussion about the "mortgage credit channel" of the 2008 financial crisis (Mian and Sufi, 2009). However, it is intriguing to revisit Case and Shiller (1989), who already speculated in their seminal paper that the forecastability of housing prices and housing excess returns could be nothing but a function of the forecastability of real sovereign interest rates or of mortgage rates.[34] Meanwhile, in the appendix, we will consider another key variable for which our regressions suggest some plausibility, and our primary sources provide new detail: housing supply estimates through the ages.[35]

7.5 Housing credit: mortgage rates

Specifically, given that our regression results suggested a potentially decisive role of credit availability for the formation of housing returns, we analyze long-run trends in mortgage interest rates – one of the oldest financial asset classes in advanced economies.

For this purpose, we utilize a comprehensive dataset that specifically collects German mortgage rates, including for the exact subset of cities that constitute the repeat sale price index. This mortgage dataset features more than 1,100 observations and is described further in Schmelzing (2025). Marketable long-maturity mortgages are one of the oldest financial assets in European financial markets (not least since they were compatible with the Church's usury doctrine), and we display a representative contract in the dataset in the appendix.[36]

German mortgage interest rates represent a trend stationary series displaying a general downward trend, and per Table 6 record a structural break on the nominal basis in the year 1685. This break in 1685 is echoed when testing the real mortgage basis, where breaks are revealed for 1666 and 1799.[37] We visualize German real mortgage rates via Figure 10, showing this secular downward trend. Over the period of 1666-1799, real German mortgage rates fall by 7.7 basis points per annum, over the period 1799-2022 real German mortgage rates moderate their decline slightly, and display an average 7.3 basis point decline. In general, however, these results confirm recent evidence from sovereign real interest rates: over longer horizons, sovereign real interest rates have been shown

[34] See in particular their Table 3 and associated discussion.

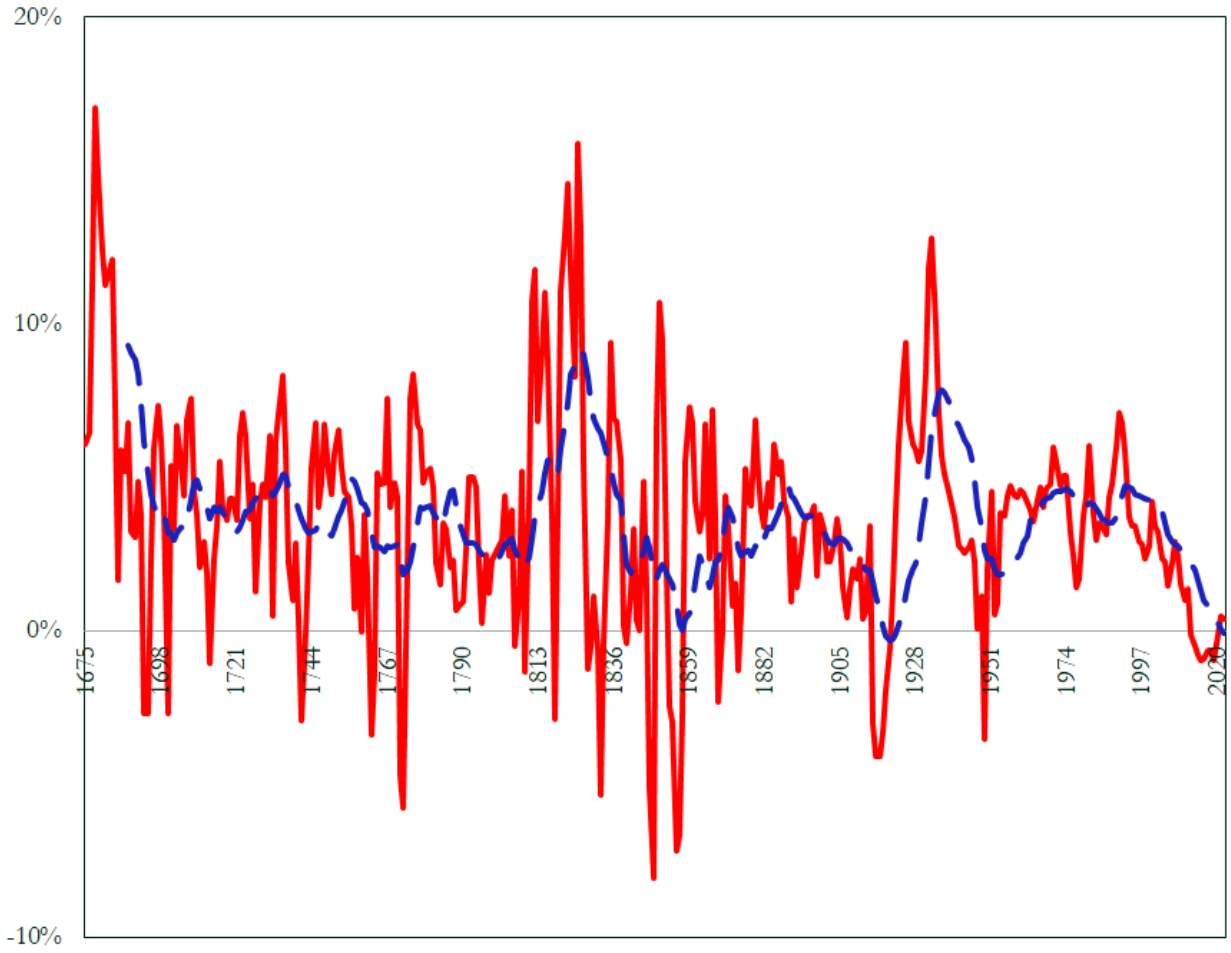
[35] For this housing supply exercise, see Appendix section 5. In recent literature, one of the key recognized drivers of house price and total return variation is indeed housing supply. For instance, in U.S. data, it has been recognized that recent decades saw a rise in regulatory interventions into land and housing markets, adversely influencing supply – one consequence being that house price booms were increasingly detached from actual building booms (Ganong and Shoag, 2017).

[36] See Figure

[37] The real basis uses the seven-year progressively lagged German inflation rates in Rogoff et al. (2024) which follows constructions in related literature. See Appendix tables A.6 and A.7 for ADF-GLS tests on German mortgage rates, as well as sovereign rate-mortgage rate spreads over time.

to be trend stationarity around a downward trend, with relatively few breaks over centuries and relatively short half-lives. The same appears to be the case for mortgage rates, at least on the German data basis. It is a plausible result in light of the evidence on time series properties of house prices, though famously such tests have been conducted on much narrower data by Case and Shiller (1989).

Figure 10: Real mortgage rates, Germany, 1685-2022.



Notes: The Figure displays German real long-maturity mortgage rates on a consistent concept basis, as reported by Schmelzing (2025). The inflation adjustment approach follows Rogoff et al. (2024), using a seven-year progressively lagged German inflation rate. The blue line displays the Müller and Watson (2018) trend component.

The comparison with sovereign real interest rates turns us to excess return considerations. Excess returns typically take "safe" sovereign returns as their reference point, and thus such an exercise can be undertaken for the very long run, on the German data basis.

Figure 11 displays log excess housing returns over the period 1465-1910, pre-tax. The measure takes the spread between public returns (long-maturity sovereign rates) and private ones (housing total gross returns). For Germany, both components of this spread – the public long-maturity rate and the housing returns constructed in this paper – can be measured in unusually granular terms and thus lend themselves to such an exercise.

Indeed, we observe that, apparently, these excess returns were positive prior to circa 1515, then turn negative over around one-and-a-half centuries (1520-1685: -2.2%), before entering a secular upwards trend. These are statements that can and will be tested more rigorously via econometric exercises – but for now, we note that excess risky returns appear to have grown sharply between the end of the Thirty Years War and World War One, when they stabilized at levels close to 5% p.a. This latter level is remarkably close to estimates for the modern period: Jorda et al. (2019), for one, calculate the advanced economy log excess pre-tax return for housing over 1870-2020 to be 4.4% p.a. over long-maturity sovereign bonds.

In any case, what the evidence from credit markets appears to show is that the "recent" fall in mortgage rates that has been put at the core of explanations of the 2000s housing boom and its subsequent crash (Justiniano et al., 2019) has in fact deep historical origins. That is, our structural break analyses did not reveal some point during the 1980s or 1990s as constituting a relevant inflection point in real mortgage rates. Instead – echoing new evidence from sovereign credit markets – it appears that significant continuities exist in fixed income markets, with continuous downward trends and trend stationarity features being confirmed for all of them. To be clear, while our results are confined to Germany only, the literature has generally posited strong correlations between advanced economies, and therefore future research could strengthen our basic observation of a positive correlation of German house prices with other European constructions.[38]

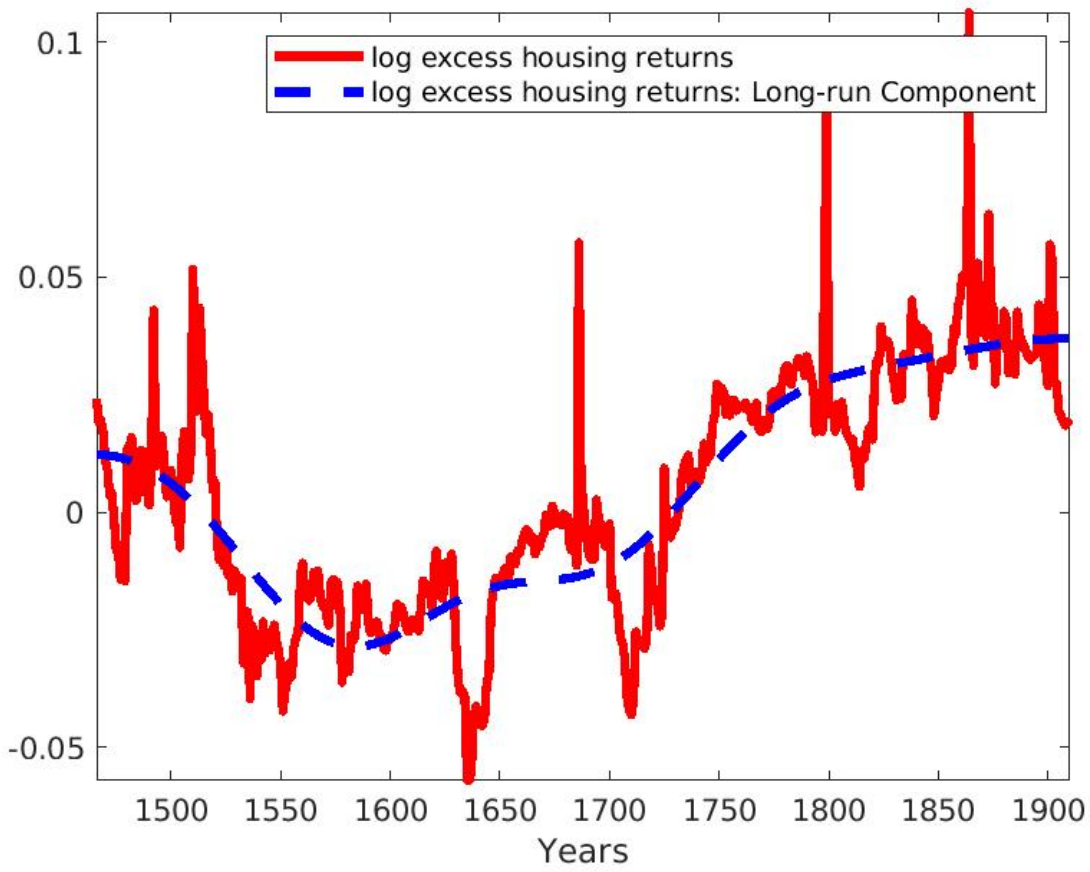
8 Conclusion

Very recent leaps in both primary source availability and machine learning models now allow for far more nuanced asset pricing reconstructions, and enable a rethinking of many stylized facts in the financial universe. In this paper, I took advantage of the German data situation in particular, which allows some of the most granular housing stock empirical reconstructions over the the long-run: this paper utilized crucial data advances in the accessibility of such data over the most recent years. Combining such data with machine learning models – for which I utilize long-run covariates reconstructions, including building cost indices –, I provided the first housing price and total return series for global housing markets over centuries. It attempted to establish a number of new stylized facts for this asset class, including its rather idiosyncratic secular risk dynamics relative to sovereign interest rates or equity returns.

On the basis of a new granular house price index – one that replicates "state of the art" indices and addresses various methodological drawbacks in historical literature – we for the first time assessed the truly "long cycles" in global housing and first established that the well-documented real and nominal house price appreciation over the past years in fact appears to have deep secular roots, and one key "long cycle" precedent (1650-1790). Much points to the Great Depression as the inception point of the current, ongoing 21st century global housing boom – though we

[38] For instance Eichholtz et al. (2021) show high degrees of correlation (.75) on the gross yield side between Paris and Amsterdam, over 1900-1943.

Figure 11: Log excess housing returns, Germany, 1465-1910.



Notes: The plot depicts German log excess housing return, relative to German long-maturity sovereign returns, both series pre-tax. The blue line depicts the long-run component of excess returns, using the methodology of Müller and Watson (2018).

generally fail to identify structural breaks in the mid-20th century using conventional tests, with a variety of series in fact displaying a remarkable absence of robust structural breaks over centuries. Importantly, we also found meaningful evidence questioning stylized facts in seminal housing literature that posit income growth to excess house price growth in "normal times". Rather than reflective of "bubble conditions", it appears that an alternative narrative would identify the late 1990s as a "return to normal". While our new data only applies to Germany – and is agnostic about the question whether quality-related improvements may be behind much or in fact all of the long-run price dynamics – it is plausible to assume closely comparable trends for other advanced economies, given general evidence of cross-country correlations.

On the return side, housing returns appear to have followed a secular "U-shape", with a sharp decline during the 16th and 17th centuries, before assuming a secular ascent, and then losing the period at excess return levels of 4-5%. Real mortgage rates began to secularly decline since the 17th century, and to the extent that contemporary research has identified real mortgage rates at the core of house price dynamics, the underlying trends in credit supply factors apparently feature

deep historical origins, too.

Zooming into long-run asset pricing, this paper then contextualized the role of real estate in the asset universe and analyzed the very long-run spread between public and private long-maturity asset returns, a measure that is synonymous with constructing a key long-run financial market "risk premium". We observed that this risk premium is secularly increasing, with public long-maturity assets first yielding less than comparable private sector assets in the early 16th century. Is this development driven by an increasing safety of the public sector, or rather increasing risks in the private sector? We introduced new long-run series that measure the idiosyncratic risks of residential housing, adopting contemporary "fire sale frequency" measures: remarkably, we found that idiosyncratic risk in residential housing appears to have been surprisingly stable over the past three and a half centuries (following a highly volatile era): fire sale frequencies of 6-7% p.a. are extremely close to those recorded in U.S. data as of the late 20th and early 21st centuries. At the same time, all evidence points towards secularly decreasing sovereign asset risk, continuing well into the present era Schmelzing (2025). Linking our new data for the most important item in the capital stock over time – housing – with evidence from the rest of the asset universe it appears therefore, that indeed the sovereign sector has been the "driving force" in secularly rising financial risk premia.

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Table A.1: Overview of sources for Housing Index, repeat sales

	# Source	period	Source type	information
Erfurt	Hartung (1861)	1300-1700	Secondary, cadaster	F
Stengberg	Scheiber (1948)	1465-1860	Secondary	F, N
Mainz	Schaab (1841)	1604-1808	Secondary	
Frankfurt	ISG	1378-1845	Primary, archival	F, N
Koblenz	Gillissen (2016)	1408-1792	Primary, archival	
Berlin	Lüdicke (1933)	1681-1850	Secondary, cadaster	
Coburg	Wolter (2010)	1400-1945	Primary, archival	N, A
Munich	Stahleder (2006)	1368-1571	Secondary, cadaster	F, N, Q
	Burgmaier and Schneider (1966)	1572-1904	Secondary, cadaster	F, N, A, Q
Freiburg	Flamm (1905)	1572-1904	Secondary	
Dessau	Brückner (1989)	1693-1933	Secondary, cadaster	Q
Nuremberg	Topo N	1492-1910	Primary, archival	F, N, A, Q

Notes: The table reports underlying sources for repeat sales observations. For column 5, the following codes are used: F = contains explicit foreclosure events; N = contains additional information on non-sale transactions (such as inheritances or transfers within families); A = contains details on assessment values; Q = contains details on quality improvements.

APPENDIX

1. Details on data sources, and *Häuserbücher*

In Table A.1, we provide full details on the underlying sources used for the repeat sales observations across the ten municipalities in our German sample.

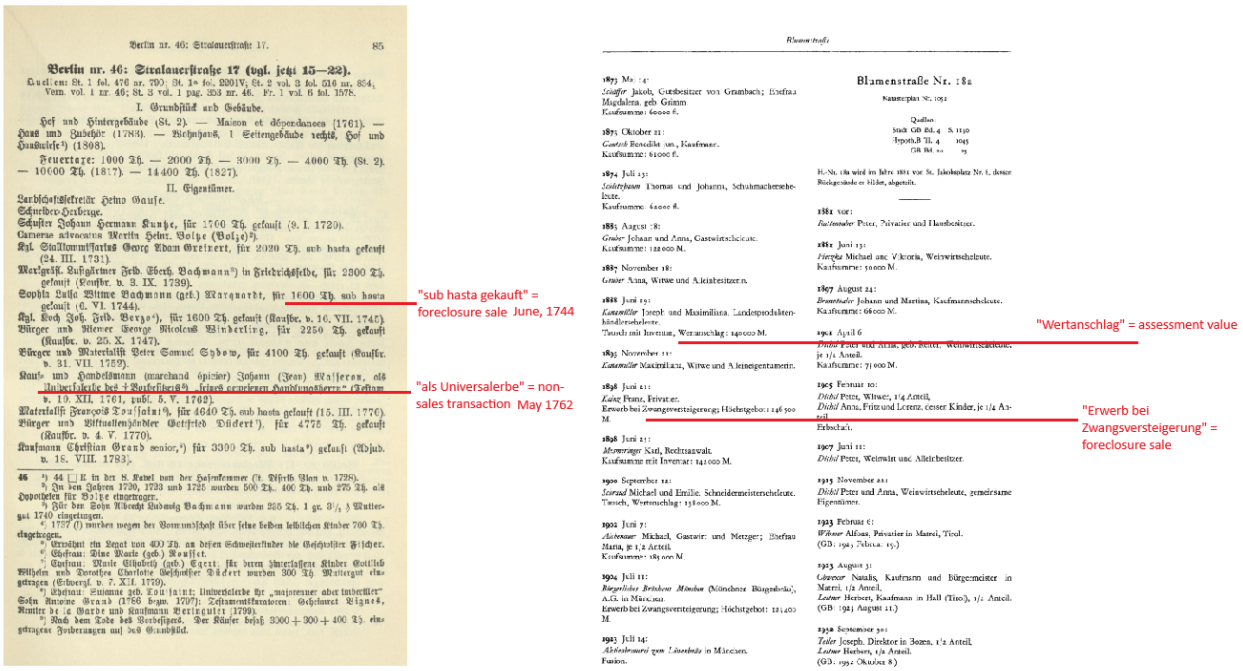
I also provide contextual details for each city – whether accompanying information such as house transfers and inheritances, details on tax assessment values (as opposed to sales prices), and quality improvements on the property level are available in each case.

Next, while we have displayed examples in the main text from the new primary source basis utilized in this study (the Topo N database for Nuremberg), the other major source type are the secondary source compilations in the *Häuserbücher*. Figure A.1 displays sample pages from secondary literature that is utilized – specifically sample pages from the *Häuserbücher* for Berlin and Munich. The left handside displays an entry for the "Stralauerstrasse 17", an address still in existence in the Berlin district of Friedrichshain as of 2024. This property documentation begins in the year 1700, and chronologically lists all associated transactions, including non-sale transactions such as inheritances (here in May 1762). Also indicated explicitly are foreclosure sales (here in June 1744), often denoted with the legal phrasing of a "*sub hasta* sale" in historical sources.

On the right handside, we display an entry from the Munich counterpart, here for the Blumenstrasse 18a, an address also in continuous existence as of 2024, in the Munich district of Altstadt-Lehel. In this case, I also highlighted an example of a *Wertanschlag* – an official assessment value of the property, as opposed to a sales price. Such assessment values are documented frequently in the *Häuserbücher*, but I do not use them for the construction of price indices, given a rage of potential (and well-documented) biases arising

from such assessments. As in the Berlin case, the Munich sources also explicitly identify foreclosure sales, highlighted here for the Blumenstrasse in 1898.

Figure A.1: Example entries from the Berlin (LHS) and Munich (RHS) "House Books".



Notes: The picture displays an extract from the Berlin house book (Lüdicke, 1933) on the left handside (LHS), and an extract from the Munich counterpart (Burgmaier and Schneider, 1966) on the right handside (RHS), together with representative examples on the details these sources provide. In particular, I highlighted inheritance events, and foreclosure sales ("sub hasta") in both cases.

Table A.2: Overview of housing expenditure share estimates

	Source	period	EXP share	coverage
Paris	Eichholtz et al. (2021)	1809-1943	25%	
Amsterdam	Eichholtz et al. (2021)	1900-1979	31.8%	M+C
U.K.	Chambers et al. (2021)	1901-1983	32%	M+C+T
U.S.	Eisfeldt and Demers (2022)	1986-2014	35%	
DMs	Jorda et al. (2019)	1870-2018	"About one-third"	
Elberfeld	Eberstadt (1903)	1891-1901	32.6%	M+C+I
Berlin	Müller (1881)	1870s	20.7%	M+C+I+T

Notes: The table reports estimates for the non-tax housing expenditure share for various geographies and historical periods in secondary literature, together with details. The EXP share in column 4 is expressed as a percentage of the property income, excluding taxes and vacancy adjustments, unless otherwise noted in column 5. Column 5 denotes the components included in the expenditure share by the respective authors: "M" = Maintenance; "I" = Insurance; "T" = Taxes.

2. Details on input estimates: expenditures, taxes, rents

Here I provide details about key inputs in the housing total return series, in particular the non-price components, on which even recent literature relies more on unobservables and generated informed estimates, as opposed to relying on direct property level data.

Table A.2 begins by presenting estimates of total expenditures associated with residential housing, as a share of gross rent. We observe that literature dealing with 19th and 20th century data has operated with relatively similar assumptions on this expenditure component across advanced economy cities, with shares ranging from 21-35% of rental income.

3. Comparison with Knoll et al. (2017), and variations of inflation bases

First, we will compare our German house price index directly with the index in Knoll et al. (2017). The latter index is representative for the authors' claim, made for Germany and the advanced economy sample as a whole, that (real) house prices inflected around the middle of the 20th century, after having been "stagnant" in the decades since 1870.

The empirical basis of German house prices in Knoll et al. (2017), however, is less than satisfying for several reasons. Not least, the pre-1914 data is based on only two cities, Berlin and Hamburg. Indeed, prior to 1903, only selected years only for Berlin are used, using the statistical yearbook of Berlin (1892).

In the main part of the paper, I stressed that various results operating with real variables (real house price index, real price gains upon sales) could be sensitive to the precise price index used to inflation adjust the nominal values.

In particular, the role of the Thirty Years War and the associated "Kipper- and Wipper" inflation shock over 1620-22 could bias results.

We are presenting transaction prices in real terms via Table A.3. Afterwards, via Table A.4, I report correlation statistics for the new German House Price index (in nominal y-o-y change) as compared to other

Table A.3: Repeat sale housing transactions, prices, real				
	# of transactions	avg. price %	median price %	Avg holding period
Total				
1300-1943	841	25.1	13.5	33.8
1500-1850	679	12.6	12.6	36.4
1700-1850	426	38.8	17.8	37.0
1800-1943	320	73.8	20.6	27.2

Notes: The table reports summary statistics for market sales transactions of houses in the sample. Average and median price columns record price increase (decrease) relative to most recent previous recorded sales price, in real terms. The nominal price change is adjusted with the cumulative change in the price index over the holding period between the sales transactions, taking the closing index value in the year prior to the sales year. Average holding period in years.

Table A.4: Correlations new German house price index and returns, existing constructions			
	period	correlation	source
Total			
GHPI – Amsterdam, annual index change	1689-1748	.181	Korevaar (2021)
GHPI – Paris, annual index change	1810-1910	.093	Eichholtz et al. (2021)
GHPI – Germany, annual index change	1871-1910	.014	Knoll et al. (2017)
GHPI – U.S., annual index change	1891-1910	.099	Lyons et al. (2024)
GHPI – Paris, log total returns	1810-1910	.109	Korevaar (2021)

Notes: The table reports correlation statistics between the new German House Price Index (GHPI) introduced in this paper, with several existing historical indices. All index correlations in nominal terms, except U.S. correlation in real terms.

historical house price indices in recent literature. It is of course not to be expected that high degrees of correlation should exist – but such measures at least provide a first indication to what extent our results could be representative for broader samples of advanced economies over longer periods of time. Per the table, we generally observe low but positive correlation values when comparing the GHPI nominal changes to historical indices for Paris, Amsterdam, and Germany.

4. Value weighted index

Prominent repeat sales house price indices are constructed on a price-weighted basis, including the prominent Case-Shiller index for U.S. cities (Corelogic, 2024). For the Case-Shiller index, in the words of the creators follows the following approach (Corelogic, 2024): "The composite home price indices are analogous to a cap-weighted equity index, where the aggregate value of housing stock represents the total capitalization of all of the metro areas included in the composite. The numerator of the previous formula is an estimate of the aggregate value of housing stock for all metro areas in a composite index".

While such a methodology has a different set of potential drawbacks, it could be relevant to test whether high level differences exist to the arithmetically weighted index presented in the main part of the paper.

In this subsection, therefore, I present the main German index on such a comparable price-weighted basis – with an index rebasing every year based on shifting value weights. Each individual home enters the aggregate index sample with its own weight – that is, there is no arithmetic weighting on the city level – thus also analogous to the Case-Shiller methodology. Interpolated home values are used for all annual observations in between actual transactions.

Figure A.2 displays this value-weighted version, for the two inflation adjustment approaches. When comparing this value-weighted version to the arithmetically weighted version in the main part of the paper, we observe that once more, the index adjusted with the lagged inflation figures in Schmelzing (2025) for Germany (blue line), a steep dropoff in real housing prices is observable at the time of the outbreak of the Thirty Years War and the associated "Kipper- and Wipper" inflation shock (here from a 1620 index value peak of 95.1 down to a bottom of 15.6 for the year 1628). The general secular trends before and after this inflection point, meanwhile, are comparable across both weighting approaches, but they suggest that the arithmetically weighted version could lead to an over-representation of lower value housing, for which price growth appears to be higher over time. Indeed, for both inflation approaches. For instance, in the period of 1466-1617, the arithmetically weighted versions suggest a real house price index increase of 50-150% (Schmelzing and Pfister inflation bases, respectively) – while the value-weighted versions suggest cumulative real price growth over the period of -7 to +46%. We reach a terminal value for the Schmelzing (2025) inflation adjusted basis in the year 1910 of 197.8 compared to 375.5 for the arithmetically weighted version; the Pfister (2022) inflation adjusted version (red line) on the other hand records a terminal value of 5,226 for the arithmetically weighted version, compared to 2,746 for the value-weighted version. In all cases across all versions, we take the index inception as 1465=100.

5. Housing quality – and residential housing supply estimates

As we mentioned briefly in a preceding section, it is crucial to note that all existing housing indices of relevance here are agnostic regarding the role of quality-related improvements in the housing sample being measured. That is, it might well be that much if not most of the positive index changes over time could be capturing representative house improvements.

Characteristically, Knoll et al. (2017) state that:

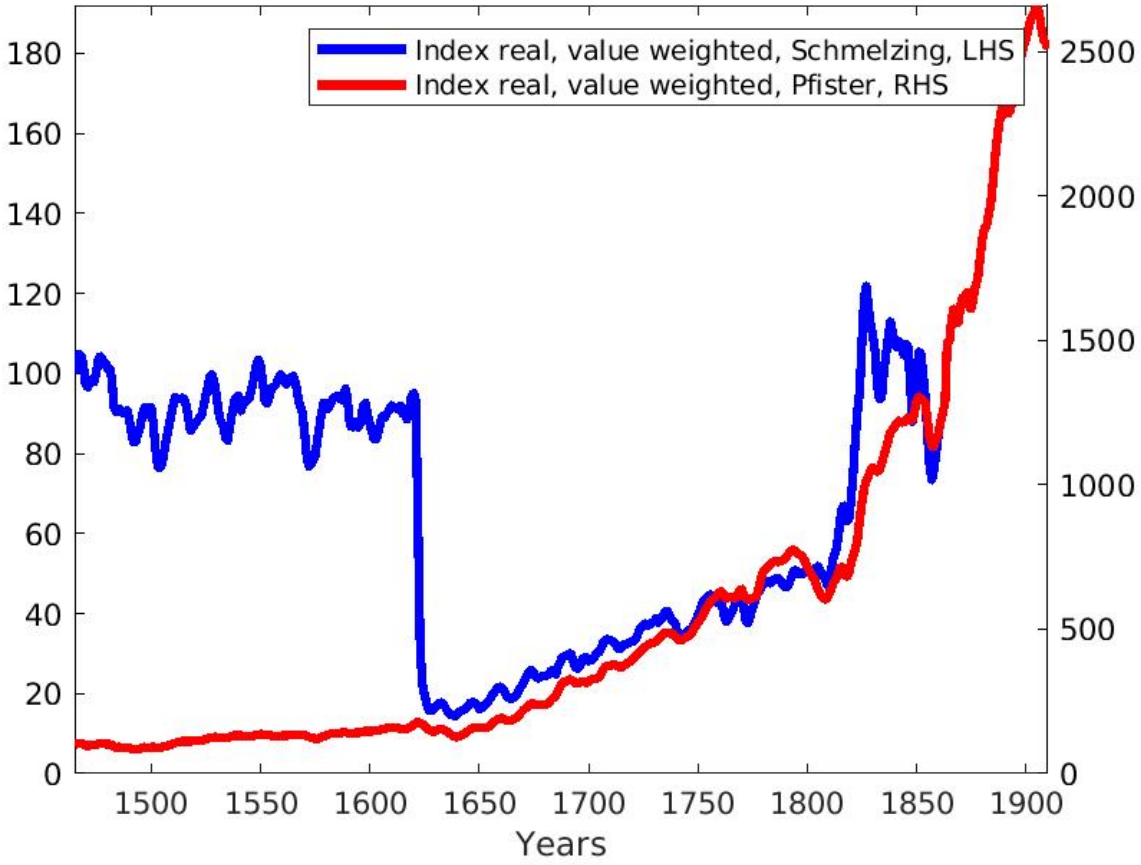
- "researchers using our dataset in the future should take into account that accurate measurement of quality-adjustments remains a challenge."

These authors – in line with preceding work – make no quality adjustments for price indices in the early part of their sample, but splice early observations with quality adjusted series in the second half of the sample. Our basis is therefore consistent in that no principal quality adjustment is made: conceptually, that is of no concern for any of the preceding or subsequent discussions, though of course it would be *desirable* to know precisely the underlying decomposition in quality-related price changes and the residual components.

Yet, we can at least sketch the general contours and focus on two recognized major quality measures for which long-run analyses are feasible: specifically, floor space per capita, and heating.

Key contributions decomposing the "quality" input into residential housing have posited that the floor area per capita and the number of rooms constitute major ingredients for housing quality, for both renters and owner-occupiers – and indeed a statistically more significant one compared to factors such as neighborhood, schooling, or crime indicators (Kain and Quigley, 1970). This is in particular true for existing long-run

Figure A.2: Value-weighted housing index, real, 1465-1910.



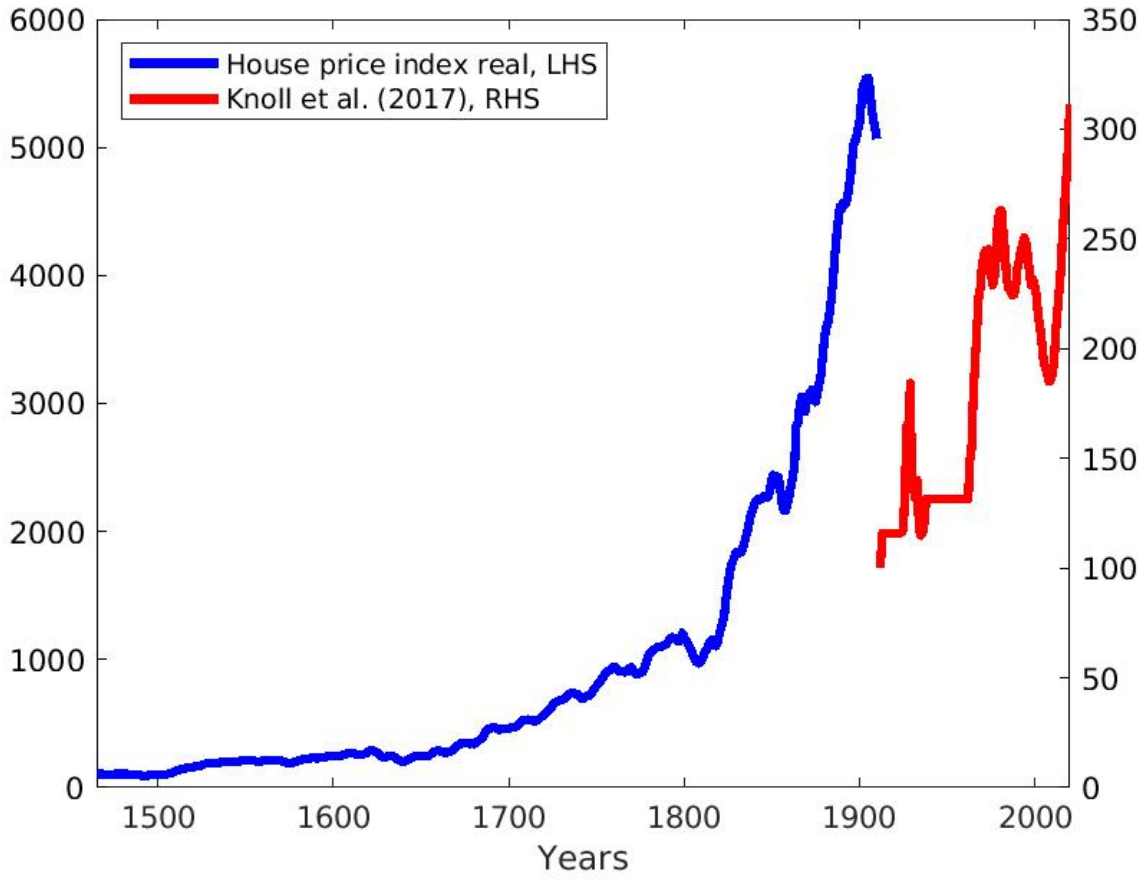
Notes: The Figure displays value-weighted real housing index, taking 1465=100. Two inflation bases are shown, the Pfister (2022) basis (in red, RHS), and the Schmelzing (2025) basis (in blue, LHS). Rebasings are every year, with interpolated housing values for each house in the sample outside of transaction years.

studies which try to devise constant-quality indices, and which emphasized floor space per capita as a dominant input (Clark, 2002; Eichholtz et al., 2022).[39] Given that the *Häuserbücher* frequently inform us about house level parcel and floor sizing, we can derive some long-run statistics on representative quality changes on this key indicator: we know, for instance, that the Berlin houses in our sample run at an average 417 square meter parcel size, and know that in the two districts from which our houses are drawn (Dorotheenstadt and Friedrichstadt), persons per house are calculated at 14.9 for the year 1711, yielding a square meter living space figure of 28 per capita. The appendix more systematically lists sources and chronological estimates for all cities.[40] Overall, however, the data suggests that it is not implausible to

[39]As Eichholtz et al. (2022) state, "housing quality per capita [is] most relevant when discussing the evolution of the standard of living. Such concerns are relevant: Adam Smith explains the relative affordability of London housing as the result of mass-scale sub-letting of parts of dwelling homes (Smith, 1776). Smith's observation suggests that the number of people per house may have varied substantially across cities (and potentially over time). To address these concerns, we need to look at housing space per capita." And similarly, via Clark (2002), "to estimate housing rental values while controlling for quality, I have used the subset...of the observations where there are multiple observations on the same property at different times, and no indications of change in size or quality of the structure, or of change in lot".

[40]Earlier house and parcel sizes in Germany are typically measured in "Ruten" (1 Quadratrute = 14.1846 square

Figure A.3: German real house price index, 1465-1910. Relative to Knoll et al. (2017) index 1910-2020.



Notes: The plot depicts the new German house price index, in real terms (blue, LHS, using the Pfister (2022) inflation adjustment). This index is shown in context to the Knoll et al. (2017) real house price index for Germany over 1910-2017, in red (RHS, here 1910=100).

assume an increase of representative floor space per person in German urban areas by a factor of 2-2.5x between the early 1500s and the early 21st century – from levels between 15-20 square meters in the era prior to the Thirty Years War, to contemporary averages of 38-40 square meters based on most recent census data for key German cities. That is an increase that falls far short of the increases in real property level house prices over the same period when using arithmetically weighted indices – however, interestingly, value-weighted indices suggest that living space growth could account for a not insignificant share of overall real price growth. Specifically, our value-weighted RHPI that fuses JST data post-1910 records a full-sample increase in real house prices of 3.9x over 1465-2020. To the extent that the sample over time captures "representative" housing samples, this suggests that living-space adjusted real house price growth on such a basis would only account for the residual 1-1.5x in real price growth.

Another approach leverages advanced artificial intelligence models to estimate changes in living space. For a variety of our housing units, more or less professional imagery exists that documents the evolution of (exterior) housing characteristics over long periods of time. An example is the situation for Munich,

meters) or "Fuss" (1 Fuss = 0.313 meters). See Table A.5 and associated discussion in Appendix section 5.

which can utilize the architectural drawings by Gustav Schneider printed in the Munich *Haeuserbuch* that reconstructs the exact visual appearance of same housing blocks over centuries.

Repeat-sales housing indices are considered as the best construction method to incorporate quality changes in housing assets – but they still remain subject to potential quality-related distortions. In general, the literature has settled on preferring repeat-sales indices to control for many quality-related changes in housing, but acknowledges that no perfect methodology exists to fully separate "true" housing index changes from housing quality changes. Indeed, some key literature dealing with long-run construction has resorted to simply acknowledging the potentially distorting role of quality changes, but gone ahead with splicing quality-controlled with non-quality controlled sub-indices (Knoll et al., 2017).[41]

For even longer time series, the potential role of quality adjustment of course rises further. As in previous literature, I therefore emphasize that even in our repeat-sales basis, the pre-1910 trend in rising real house prices in Germany could still be driven mainly by quality improvements within the same homes; subperiods of falling prices could be driven by a drop in housing quality within the same homes. But it is important to get a sense of the potential size of the quality effect, to the best extent possible. For this purpose, the following Table A.5 begins by systematically compiling available data for living space in early modern and modern German cities, converted to a per capita basis. I only include data points where authors refer to "typical" or "representative" housing units in the respective city, and have included precise space data.

Here we observe that there appears to have been a clear upwards trend in living space per capita in German urban areas over the very long run – perhaps an intuitive general observation. Our earliest data points indicate typical living space of around 15 square meter – a figure which then rises over the course of the early modern period, and by the eve of the Thirty Years War rose above 20 square meters for the first time. From there, another doubling of average living space takes place by the early 21st century, where current official city surveys for Berlin and Munich indicate living spaces per capita of 38-40 square meters.

This means that some of our housing price appreciation is likely driven by house quality improvements related to size: given homes can be enlarged, either by adding "attached houses" on the same address, or through adding additional stories, say. That both effects took place is confirmed by anecdotal evidence in our cities. At the same time, at least on the basis of the limited number of concrete data points, it is not clear that such space dynamics themselves had any decisive role per se: assuming a doubling of living space for a representative housing inhabitant in our sample over half a millennium would translate into an annual increase of living space of just 0.2%.

But perhaps additional nuance to quality improvements can be gleaned from representative micro-level evidence. Figures A.4 and A.6 actually display the evolution of representative residential housing units that are featured in our sample. These are typical units behind our numbers over time and space. In the first, we exhibit a artisan building in Nuremberg, originally built in the year 1489 for newly arriving weavers from the Nuremberg region. The buildings have undergone an eventful history, but are still located at the same place in Nuremberg today, keeping the same address at the *Sieben Zeilen*. Thanks to in-depth studies by the Nuremberg Historical Association (Taschner, 2013) we have extensive detail about the precise quality adjustments and architectural details of the buildings.

The building contains two stories, with an additional roof area used for storage purposes, as well as a

[41] Knoll et al. (2017) acknowledge the fact that their indices may insufficiently control for quality dynamics, especially in the pre-1945 era, and write that "researchers using our dataset in the future should take into account that accurate measurement of quality-adjustments remains a challenge." For Germany, the paper claims that the pre-1945 data is non-quality controlled, while from 1962, their nationwide index controls for quality changes.

Table A.5: Average or representative living space estimates, German cities

	Source	period	sqm per capita	type detail
		Early Modern Era		
Nuremberg	Dirlmeier (1978)	1488	15	representative M and LM
Augsburg	Weidenbacher (1926)	1516	16	representative LM
Lemgo	Kaspar (1985)	1400-1650	17.6	
Cologne	Eberstadt (1903)	ca. 1620	20.3	"typical three-window house"
Berlin	Voigt (1901)	1711	28.1	representative UM and M
Frankfurt		1855	25.1	representative M
Vienna	Lichtenberger (1977)	1856	16.8	weighted avg, inner city
		Modern Era		
Berlin	Berlin (1897)	1890-5	31.4	all-city average
Wolfen	Wilde (1999)	1872-1908	27.5	representative M and LM
Munich	Renaud (1904)	1903	9.3	all-city average
Giessen	Meyer (1903)	1900	20.4	representative M and LM
Frankfurt	Schuette (1930)	1930	37.0	Housing office Frankfurt
Berlin	Grundstuecks-MB	1946	11.8	all-city, census data
Berlin	Grundstuecks-MB	1996	34.8	all-city, census data
Berlin	Grundstuecks-MB	2000	37.9	all-city, census data
Berlin	Landesamt (2022)	2022	40.7	all-city, census data
Munich	SAM (2022)	2022	38.4	all-city, census data

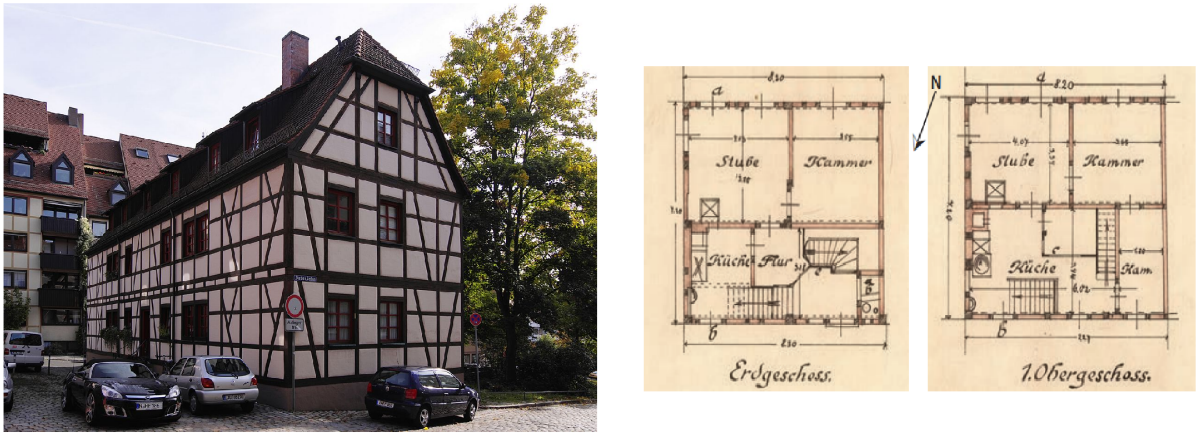
Notes: The table reports data for the residential living space per capita in contemporary and historical sources. Data prior to 1700 operates with average household size of 3.3 persons. um = upper middle class; M = middle class ; LM = lower middle class. The Vienna figure takes midpoints of the range in Lichtenberger (1977), and inner city population figure of 1834.

cellar containing work areas. Two households lived in such a building from the inception date. Per the architectural drawing displayed on the right handside of Figure A.4 – itself produced for a renovation project in the year 1912 – we know that the living space per story stands at 59 square meters (8.2 meters width, 7.2 meters depth, including staircases). Such dimensions are comparable with corresponding information from other German urban areas in our sample and beyond. Adjusting the living space for household size developments for urban middle class households yields several relevant data points for living space per capita.

Next, Figure A.6 displays a representative residential street in Munich, shown in its condition in the year 1939. We observe that by the 20th century, residential houses in larger German cities feature four to five stories, including attics. At this time, one can assume three to four households per residential unit, that is 12-20 persons in a representative residential building, per Burgmaier and Schneider (1966). These residential units again contain unit-level heating, hot water, and kitchens. In the ground floors, we often find commercial real estate, and shared cellars are typically included below ground floors. The street length is about 80 metres, and the depth is 11 metres.

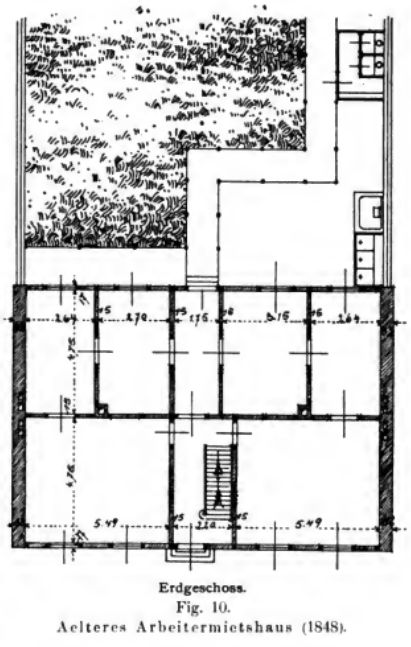
Today, the buildings in the *Blumenstrasse* remain in place, and can be located at geoportal.muenchen.de/portal/plan – coordinates 11° 34 16|48° 07 55.

Figure A.4: Representative middle class residential house, built 1489, Nuremberg.



Notes: The Figure's left handside displays the exterior of a representative Nuremberg middle class home, located at the *Sieben Zeilen*; the left handside displays the corresponding architectural drawing, sourced via Taschner (2013).

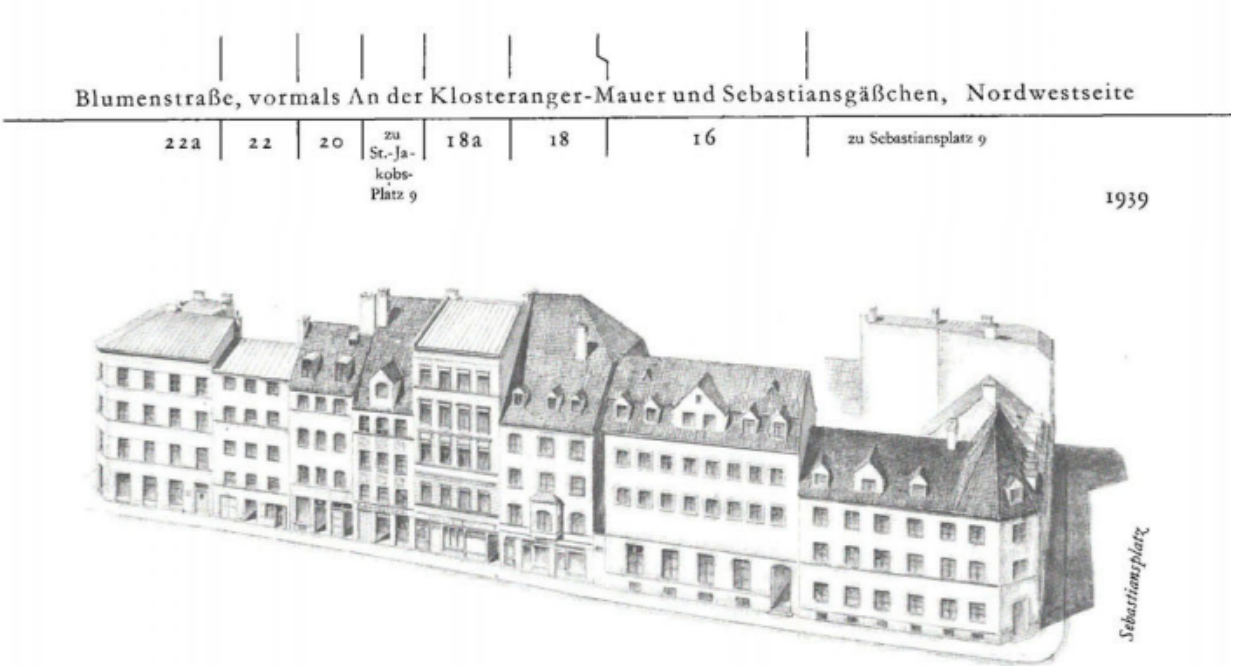
Figure A.5: Representative lower middle class residential house, Rhineland, ca. 1848.



Notes: The architectural drawing from Eberstadt (1903) displays two representative middle class house types in the Rhineland, 1848. The house contains three storys, with two units per story. Displayed is the ground story, with the added backyard. The measurements per unit are 5.48 meters by 9.52 meters = 52.3 square meters of living space per unit.

Over the (very) long-run, the precise evolution of housing supply and the connection to secular price and return trends remains virtually unexplored. Even influential recent contributions (Knoll et al., 2017) made no attempt to understand better the *drivers*, including supply side drivers, of housing boom episodes – or to incorporate supply trends. But such an exercise can provide a first glimpse into the evolution of housing quality, specifically the component of living space per capita.

Figure A.6: Representative middle class residential street, 1939, Munich.



Notes: The architectural drawing from displays a typical street of residential houses in Munich, shown in their condition as of 1939 (*Blumenstrasse 16-22a*). Architectural drawing by Gustav Schneider in Burgmaier and Schneider (1966).

For Germany, it is fortunate that new data for German urban housing stocks exist through the work of Zwierlein (2021): the latter systematically compiled housing stock statistics in order to analyze the severity of urban fires, using primary sources. Between 1401-1962, 101 matched data points exist for both the urban housing stock and the total population in the same year and city.

Presumably, the number of housing units per building, and floor space per unit, could have undergone dramatic secular changes. Figure A.7 displays this data over the period. In general, we observe that the data appears to indicate a moderate decline in the first quarter of the sample, roughly the period of 1450 until the middle of the Thirty Years War. Afterwards, an equally moderate but continuous increase of the ratio emerges, with some indications that a sharper increase takes hold from the mid-19th century.

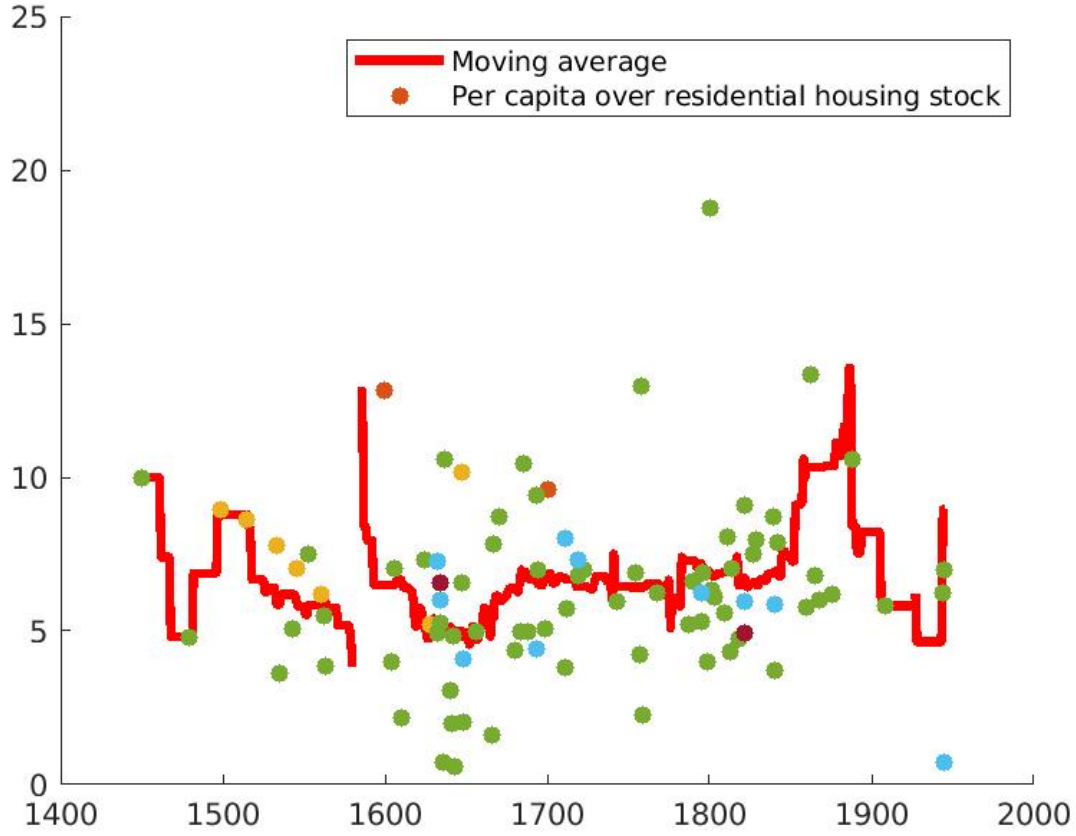
Of course, such a broader aggregation of urban residential housing stocks does not reflect potentially decisive dynamics in housing *size*. Single-family units could have been replaced by spacious multi-family units, and the typical single family unit could have substantially grown in size, de facto increasing living space. There is no systematic study on the evolution of housing unit size over the long run – but there is a panoply of individual information in city level contributions, which can be aggregated. To address the size evolution, we therefore utilize such historical sources. Detailed urban building histories exist for a sufficient number of representative – and at times directly overlapping – cities that can inform us on such trends, and enable a merger with the housing stock figures.

The general contours of housing size are known in urban history literature. For instance, prior to the 17th century, lower and middle income residential houses rarely featured more than two living floors (first and second floor). High income units on the other hand, featured up to three floors – and in addition occasionally featured additional attached rental housing on the same land parcel.[42] Multi-story buildings,

[42]For instance, for early modern Lemgo, Kaspar (1985) estimates that 15% of all residential housing included such

featuring five and more floors, emerge in the second half of the 19th century in our city sample. The appendix systematically displays "typical" residential buildings from urban histories that lie behind the bare numbers in our subsequent statistics, and which allow precise adjustments on the number of units, household size, and square meter footage per capita over time.

Figure A.7: Residential population over residential housing units, German cities, 1465-1961.



Notes: The plot depicts the ratio of residential population over residential housing stock (in numbers of residential buildings). Data is mainly calculated on the basis of Zwierlein (2021)'s urban fire statistics. The green line represents a moving arithmetically weighted centered 35-year average across the sample.

6. Variable importance, and Building cost index details

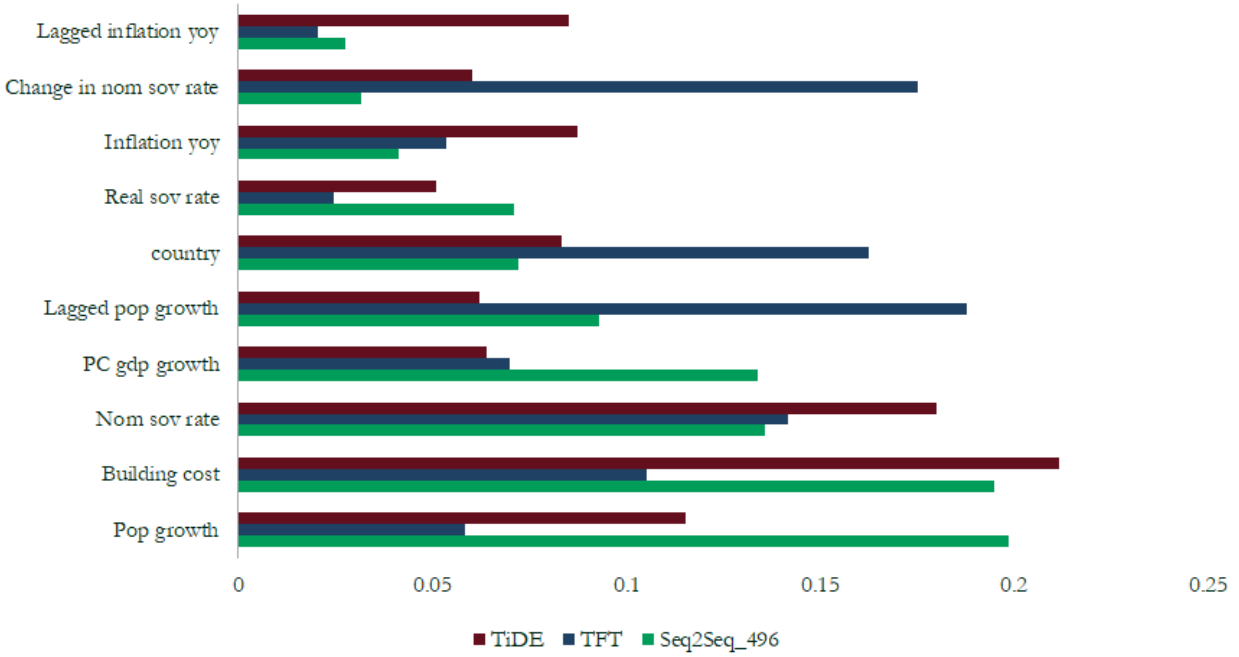
Via Figure A.8, we provide the variable importance, by model, for the machine-learning methodologies. The importance refers to the training dataset that utilizes 1870-2020 data, across the three machine-learning models – Seq2Seq, TFT, and TiDE. The former (Seq2Seq) constitutes the "baseline" machine-learning model with the highest realized Rsquared, therefore here the variable importance is most relevant.

We generally note that variable importance can vary substantially across the three models, but that a handful

attached smaller units, almost exclusively for high income owners. Also occasionally, in the case of merchant and business occupants, high income houses featured additional commercial space within the same unit.

of variables retain high important across approaches – including the nominal (long-maturity) sovereign interest rate, building costs, and population growth rate (lagged and unlagged).

Figure A.8: Variable importance by model.



Notes: Variable importance for the top-10 most influential variables in each model. Variable importance within each model is normalized to sum to one, excluding "time".

Next, we list the sources and methodology for our building cost indices, by country. As per the prior exercise, in terms of variable importance, these building cost indices – several of which we newly construct in consistent ways from raw commodity data – exhibit key relevance for the machine-learning approaches presented.

- Germany: we use the building cost index constructed by Pfister (2022), who reports index values on a quinquennial basis over 1500-1860 – we linearly interpolate annual frequencies.
- U.S.: we use the U.S. construction cost index in Adams (1975), "Variant B", reported with annual frequency over 1785-1860. The author's "Variant B" is one of several indices created for the same period – we choose this particular variant as it allows for index weight changes from substitution effects over time, rather than operating with fixed base weights ("Variant A").
- U.K.: Spanning 1661-1820, O'Brien (1985) constructs a building cost index for Britain by weighting equally (50:50) material cost changes, and construction wages. We replicate this approach for the pre-1661 data using the price components in Rogers (1902): Rogers records annual price changes for timber, bricks, lime, board, laths, crests, and slates – these seven components are arithmetically weighted to constitute the materials component; for construction wages pre-1661, we use the building craftsmen and building laborer wage data in Allen (2001).
- Holland: we use wood prices in Middelhoven (1981) for 1717-1865. To these, we add building labor costs obtained via Allen (2001) for Amsterdam. Commodities and labor costs are weighted arithmetically (50:50), identical to the approach in O'Brien (1985) for the U.K.

Table A.6: OLS Regression, Gross Housing Total Returns

	Gross TR	Gross TR	Gross TR	Gross TR
German inflation	0.0238	0.0238	-0.0236	-0.0236
	(0.34)	(0.34)	(-0.35)	(-0.35)
Real aggregate GDP growth	-0.00154		-0.0170	
	(-0.03)		(-0.38)	
Real per capita GDP growth		-0.00134		-0.0167
		(-0.03)		(-0.38)
Population growth	0.981***	0.980***	0.974***	0.957***
	(6.24)	(6.45)	(6.52)	(6.63)
German nominal rates	-0.676***	-0.676***	-0.175	-0.175
	(-7.78)	(-7.78)	(-1.52)	(-1.52)
German real rates	0.0122	0.0121	-0.0098	-0.0098
	(0.45)	(0.45)	(-0.38)	(-0.38)
PUB-PRI spread	0.217***	0.217***	0.197***	0.197***
	(5.42)	(5.42)	(5.18)	(5.18)
year			0.000093***	0.000093***
			(6.29)	(6.29)
constant	0.111***	0.111***	-0.0727*	0.0726*
	(23.10)	(23.10)	(-2.46)	(-2.46)
observations	355	355	355	355
Adj. R-squared	0.254	0.254	0.329	0.329

Notes: t statistics in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Columns 1 and 2 are not controlling for a year trend, while Columns 3 and 4 do. Real total gross return is not included as a variable given that it is mechanical. Columns 1 and 3 use German real aggregate GDP growth and Columns 2 and 4 use German real per capita GDP growth, as both measures are highly correlated and therefore cause multicollinearity issues. "PUB-PRI" spread here uses German mortgage rates for PRI basis.

7. Econometrics

Here we undertake additional tests to analyse the main paper results with regards to robustness, especially the main regressions and time series properties of the housing and associated variables.

.1 Regression variations

First, we assess variations of the excess return variation. We begin by showing variations of the main excess return regression shown in the main part of the paper, via Table 5.

In Table A.6, we replace log excess returns with gross total returns, to test whether the arithmetic basis influences results, and whether the excess spread is a result driven by the specific excess return definition.

Table A.7: ADF-GLS, housing and credit variables, no time trend

	no of lags	t statistic	optimal lag
German mortgage rates, nominal, 1311-2022	3	-6.803	Seq, MAIC
	2	-7.662	
	1	-8.940	SIC
Real gross housing return, 1495-1910	3	-2.244	
	2	-2.375	Seq, MAIC, SIC
	1	-2.884	
Real net housing return, 1495-1910	3	-2.676	MAIC
	2	-2.832	Seq, SIC
	1	-3.429	
Real house price change, 1495-1910	3	-4.286	
	2	-4.480	Seq, MAIC, SIC
	1	-5.328	
German PUB-PRI, 1311-2022	3	-3.671	Seq, MAIC, SIC
	2	-4.393	
	1	-5.018	

Notes: The table applies the methodology of Elliott et al. (1996) and reports the ADF-GLS test statistic for several choices of the number of lags k (with a maximum of three lags). The regression includes a constant. The test assumes no time trend. The critical values at the 1, 5, and 10 percent significance levels are the following: -2.58 (1 percent); -1.95 (5 percent); -1.62 (10 percent). "Optimal lag" indicates the optimal number of lags according to the sequential procedure ("Seq"), the Bayesian Information Criterion (SIC), or the Modified Information Criterion (MAIC). The test rejects when the test statistic is negative and larger (in absolute value) than the critical value.

.2 Mortgage rate and housing variable stationarity

Next, we assess the time series properties of various variables that we have introduced and discussed in the main part of the paper. Table A.7 reports results for a standard ADF-GLS trend stationarity test, via Elliott et al. (1996), not assuming a time trend. Table A.8 repeats this exercise, this time assuming a time trend.

Across all these variations, we observe that German mortgage rates, as well as excess returns (PUB-PRI), are all recording clear trend stationarity, all at the 1% significance level.

.3 City level ADF-GLS

Below we report the result for city level trend stationarity. In general, it can be observed that trend stationarity is broadly confirmed once more – however, with slightly weaker significance than the aggregate national index we constructed. Cities with fewer property units and/or short observation spans record weaker (if any) significance, including Dessau and Freiburg. This appears in line with existing results for modern city level aggregations that have found meaningfully higher volatility and noise on city level, as compared to national aggregations (Piazzesi and Schneider, 2016).

Table A.8: ADF-GLS, housing and credit variables, with time trend

	no of lags	t statistic	optimal lag
German mortgage rates, nominal, 1311-2022	3	-7.835	MAIC
	2	-8.709	Seq
	1	-10.022	SIC
Real gross housing return, 1495-1910	3	-3.396	
	2	-3.556	Seq, SIC, MAIC
	1	-4.262	
Real net housing return, 1495-1910	3	-4.037	
	2	-4.216	Seq, SIC, MAIC
	1	-5.027	
Real house price change, 1495-1910	3	-6.031	
	2	-6.178	Seq, MAIC
	1	-7.158	SIC
German PUB-PRI, 1311-2022	3	-7.019	Seq, MAIC
	2	-8.139	
	1	-8.985	SIC

Notes: The table reports the ADF-GLS test statistic for several choices of the number of lags k (with a maximum of three lags). The regression includes a constant. The test assumes a time trend. The critical values at the 1, 5, and 10 percent significance levels are the following: -2.58 (1 percent); -1.95 (5 percent); -1.62 (10 percent). "Optimal lag" indicates the optimal number of lags according to the sequential procedure ("Seq"), the Bayesian Information Criterion (SIC), or the Modified Information Criterion (MAIC). The test rejects when the test statistic is negative and larger (in absolute value) than the critical value.

Table A.9: ADF-GLS, city level, with time trend

	no of lags	t statistic	optimal lag
Erfurt	3	-5.360	
	2	-5.456	Seq, SIC
	1	-4.819	MAIC
Stengberg	3	-4.505	Seq, MAIC
	2	-5.151	SIC
	1	-6.528	
Frankfurt	3	-2.936	
	2	-3.066	Seq, SIC, MAIC
	1	-4.276	
Koblenz	3	-6.119	Seq
	2	-6.445	MAIC, SIC
	1	-8.740	
Berlin	3	-4.859	MAIC
	2	-5.580	
	1	-6.561	SIC
Munich	3	-6.829	MAIC
	2	-7.381	Seq
	1	-8.656	SIC
Freiburg	3	28.818	Seq
	2	28.716	SIC
	1	-4.499	MAIC
Dessau	3	-0.899	Seq, MAIC
	2	-0.763	SIC
	1	-0.994	
Nuremberg	3	-6.323	
	2	-6.171	Seq, MAIC, SIC
	1	-7.491	

Notes: The table reports the ADF-GLS test statistic for several choices of the number of lags k (with a maximum of three lags). The regression includes a constant and a deterministic time trend. The critical values at the 1, 5, and 10 percent significance levels are the following: -3.48 (1 percent); -2.89 (5 percent); -2.57 (10 percent). Except for Erfurt where its -3.54 (1 percent); -3.00 (5 percent); -2.71 (10 percent) , Berlin where its -3.49 (1 percent); -2.96 (5 percent); -2.67 (10 percent) and Freiburg where its -3.77 (1 percent); -2.19 (5 percent); -2.89 (10 percent). "Optimal lag" indicates the optimal number of lags according to the sequential procedure ("Seq"), the Bayesian Information Criterion (SIC), or the Modified Information Criterion (MAIC). The test rejects when the test statistic is negative and larger (in absolute value) than the critical value.

7. A representative mortgage contract

Figure A.9 displays a representative mortgage contract, dated April 30, 1624, that is part of the Schmelzing (2025) mortgage interest rate sample, shown and analyzed in our section 7.1 of the main part of the paper. Here the stated interest rate is 5% p.a.

Figure A.9: Representative mortgage contract, April 30, 1624, Freiburg region.



Notes: The image displays a mortgage contract dated April 30, 1624. It is part of the mortgage rate sample over 1311-2024 in Schmelzing (2025). The contracting parties in this case are Cleopha Mayerin zu Pfullendorf on the debtor side, and the monastery of Pfullendorf on the creditor side. Contract held in the archives of the Archbishopric Freiburg, Erzbischöfliches Archiv Freiburg, Urkundensammlung Haid UH095, in: Monasterium.net, URL </mom/DE-EAF/Haid/UH095/charter>, accessed November 11, 2024.