Housing Betas

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ABSTRACT

This paper documents new stylized facts about returns and cashflow growth rates on stocks and housing over decade-long holding periods. While cashflow growth rates on the two assets comove positively, their returns comove negatively until the Global Financial Crisis and positively thereafter. These facts present a puzzle for representative-agent models that imply positive return comovement for assets with similar cashflows. I consider a heterogeneous-agent model with segmented stock and housing markets connected through credit. News about the aggregate economy generates negative return comovement. Recent shifts such as wealthier homebuyers and institutional housing purchases reduce the importance of credit and segmentation.

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There are three broad classes of assets—stocks, housing, and bonds. Finance usually studies housing in isolation, in a separate literature (surveyed by Piazzesi and Schneider 2016). This makes sense because of market segmentation—households in the top 10% of the wealth distribution hold mostly stocks, while middle-class households buy most houses. This paper argues, however, that these broad asset classes should be studied jointly. The reason is that credit markets connect these otherwise segmented markets, creating spillovers across them. Most homebuyers borrow money to buy a house, with the levered housing position dominating the portfolio of the average homebuyer. While the typical stock purchase does not involve credit, the average stockholder also holds other assets, such as bonds.

Using broad measures of stock and housing markets in the United States, this paper documents new stylized facts about returns and cashflow growth rates over decade-long holding periods; the focus on long holding periods reflects the typical holding period for housing. In particular, the returns on stocks and housing show *negative* comovement during the post-war period until the Global Financial Crisis (GFC) and positive comovement thereafter. In other words, housing tended to have a *negative stock-market beta* until the GFC, after which the housing beta turned positive. Stock returns were high in the 1960s and during the Nasdaq boom of the 1990s, when housing returns were low. In contrast, housing returns were high during the 1950s, the Great Inflation of the 1970s, and the 2000s, when stock returns were low. In the recovery following the GFC, both asset classes had high returns during the 2010s until the COVID pandemic, when they started to decline. More recently, negative comovement has reemerged with the post-pandemic inflation episode.

The return on levered housing—the relevant portfolio position for almost all homebuyers—has an even more pronounced *negative* beta before the GFC. The reason is that borrowing costs are lower during house-price booms. During the 1950s, 1970s, and 2020s, the returns on long-term debt turned negative, while in the 2000s they stayed positive but were still relatively low. Subtracting these lower borrowing costs from the higher housing returns during these episodes further amplifies the negative comovement with stock returns.

A negative housing beta contrasts with the *positive* comovement of the cashflow growth rates of housing and stocks. While the long-horizon cashflow growth rate of housing is less volatile than that of stocks, the two growth rates are highly positively correlated. Negative housing betas are a challenge for representative-agent models that predict positive return comovements for assets with similar cashflows. Incorporating time-varying discount rates does not help address this puzzle, because they generate positive comovement in price–dividend ratios, strengthening positive betas.

I propose a simple model with heterogeneous agents and segmented markets for stocks and housing that are connected through the credit market. Housing and stocks have identical risky cashflow streams, but must be held exclusively by homebuyers and stockholders, respectively. Gains from trade in the credit market arise because homebuyers have less savings relative to the cashflows of their risky asset than do stockholders. Homebuyers offer a safe bond, collateralized by housing, to stockholders, and in exchange, they can use stockholders' savings for their housing purchase. In equilibrium, homebuyers' levered position in housing is more exposed to aggregate risk than stockholders' portfolio of stocks and bonds.

When news about the aggregate economy changes the (identical) cashflows from stocks and housing, households rebalance their portfolios, with stock and house prices moving in opposite directions. First, consider an equilibrium in which homebuyers would like to borrow more but face a binding collateral constraint. When bad news about the economy arrives, stockholders shift their portfolio away from risky stocks towards safer bonds. Their flight to safety increases the credit supply. Homebuyers take advantage of the cheaper credit, which raises house prices, while stock prices fall. We thus have a housing boom, fueled by *lower borrowing costs* and more credit, alongside a stock market slump. This anatomy of a housing boom is consistent with the empirical evidence on lower borrowing costs during episodes of rising house prices.

Interestingly, another type of housing boom can emerge in an equilibrium in which homebuyers are unconstrained: borrowing is determined not by a binding constraint, but rather by the risk-return trade-off in the levered housing portfolio. In response to good news about the aggregate economy, homebuyers would like to shift their portfolios towards more housing and leverage. However, they face stockholders who would like to rebalance their portfolios towards stocks and therefore are less willing to lend, in which case credit supply falls. For credit to expand, homebuyers must be willing to pay higher interest rates on their mortgages. Thus, we again see a housing boom with more mortgage debt, but now with *higher borrowing costs* and lower stock prices.

While news about the economy makes assets with similar cashflows either more or less attractive for a representative agent, pushing their prices in the same direction, the segmented-markets model affects investors differently through credit and thereby generates negative return comovement. With less credit or less segmentation, the mechanism weakens. In the limit, the mechanism disappears, and we converge to the positive return comovement from the representative-agent model.

Several changes in the U.S. economy provide candidate explanations for the positive return comovement after the GFC. These include the higher wealth of recent homebuyers, who I show tend to have higher incomes, are older, and spend less of their household income on mortgage payments. Longer lifespans, together with lower fertility rates, lead to an aging society, which features a larger fraction of older households with accumulated savings over their lifetimes. Moreover, institutional investors, including private equity funds and real estate investment trusts (REITS), entered the single-family housing market and bought homes at low prices after the GFC. These institutional investors channel stockholder savings into the housing market, reducing market segmentation. Finally, foreign investors increased their Treasury holdings during the early 2000s, which helped keep long-term interest rates low, and have also increased purchases of U.S. residential real estate since the GFC.

The analysis in this paper is informed by several additional facts that distinguish housing from stocks. First, housing is illiquid. Transaction costs, both pecuniary and nonpecuniary, are high in housing, while they are low in stocks. These costs lead to the long holding periods that are the focus of this paper. For example, in 2021, the average homeowner had been in their house for 11.5 years. Because only about

10% of houses trade every year, a small number of transactions determine house prices that year. These transactions involve a small subset of households, as most households are passive and do not trade in any given year. The homebuyers in the model represent this small group of active traders. An extension could study a version of the model that also features an additional type of households representing passive homeowners who perhaps have bond investments.

Second, most housing transactions involve a mortgage. In Section II, I show that over 75% of homebuyers have a mortgage, down from 90% in the 1970s. This is the reason for studying the time variation of borrowing costs and levered returns on housing, the relevant returns on homebuyers' investments. In the model, the credit market allows households to use stockholder savings to buy a house; at the time of purchase, homebuyers only need to have enough savings to make a down payment. Borrowing by homebuyers is therefore collateralized by the house, a standard feature of mortgages in reality.

Finally, housing investments are undiversified. Households do not invest in a mutual fund that holds a diversified housing portfolio. Instead, most households buy a single house. The model with segmented markets captures the fact that nonowners do not value the cashflows from the house, but does *not* capture another feature of nondiversification: capital gains on individual housing transactions differ substantially across locations—for example, average capital gains are high in San Francisco, California and low in Huntsville, Alabama both of which are both technology and innovation hubs—but share similarly large amounts of idiosyncratic risk. The large difference in average capital gains implies that households' wealth accumulation depends heavily on the performance of a single local asset in their portfolios. Incorporating this feature would be another interesting extension of the model.

The rest of this paper proceeds as follows. Section I describes the aggregate data on stocks and housing markets, presents new stylized facts about returns and cashflow growth rates, and discusses the mechanism for positive return comovements on assets with similar cashflows produced by a representative-agent model. Section II presents empirical evidence on three other differences between housing and stock investments: liquidity, leverage, and diversification. Section III presents a segmented-markets model with heterogeneous agents that generates negative comovement in returns on similar assets, as we observe before the GFC. I also establish conditions under which the return comovement is positive, and discuss their relevance for the patterns after the GFC. Section IV offers concluding remarks about the many open questions about stock, housing, and credit markets that future research will hopefully address. The Appendix contains proofs of propositions stated in Section III that characterize properties of the segmented-markets model.

I. Returns and Cashflows on Stocks and Housing

This section presents new stylized facts about the returns and cashflows on stocks and housing. I compare annual data on real returns and real cashflow growth on stocks and housing over 10-year holding periods.

A. Data on returns and cashflows

The data on stock prices and dividends come from the S&P500 index, a broad measure of the U.S. equity market, that tracks the performance of 500 large, publicly traded U.S. companies listed on the NYSE or NASDAQ. The data are from Bob Shiller's website at Yale.[1] The stock values are end-of-year values, while dividends are averages over the previous year. The sample is annual, 1930 to 2024.

The data on house prices measure the value of residential real estate from the Financial Accounts of the United States, a broad measure of the U.S. residential housing market. The data are recorded as end-of-year values since 1945. The value of residential real estate held by households (excluding nonprofit organizations) is presented in Table B101 of the Financial Accounts. Households also hold residential real estate through nonfinancial businesses, as reported in Table B104. To compute the capital gain on housing from year t to year $t+1$, I measure the value of residential real estate in year $t+1$, subtract residential fixed investment in year $t+1$ from Table F6, and divide by the value of residential real estate in year t. The sample for capital gains is annual, 1946 to 2024.

The associated cashflow series from housing measures dollar expenditures on housing services from the National Income and Product Accounts (NIPA). This expenditure series is based on data on market rents for rented homes and imputed rents for owner-occupied homes. These imputed rents are an estimate by the Bureau of Economic Analysis (BEA) of what the homeowner would pay to rent a similar home.[2] To calculate these estimates, the BEA uses rent data collected for the Consumer Price Index by the Bureau of Labor Statistics, along with housing characteristics such as location, structure type, number of rooms, and building age. Expenditures on housing services come from line 50 of NIPA Table 2.4.5, going back to 1929. The sample for cashflow growth is annual, 1930 to 2024.

Mortgage rates strongly comove with 10-year Treasury rates. To measure borrowing costs, I take the returns on 10-year Treasuries from Bob Shiller's website. I measure the return on levered housing as the housing return minus borrowing costs. I multiply the borrowing costs by 80% to reflect the typical down payment.

To compute real returns and real cashflow growth, I take gross nominal returns and gross cashflow growth and divide them by gross inflation. To measure inflation, I use the price index for nondurables and services based on lines 25 and 47 of NIPA Table 2.4.4. The sample is annual, 1930 to 2024. The 10-year returns and growth rates are geometric means and reported per year.

[1] The monthly data are in the file `ie_data.xls` from the website `https://shillerdata.com/`.

[2] In the NIPA tables, housing services are included in personal consumption expenditure, and thus in GDP. To prevent changes in homeownership rates from mechanically affecting GDP, owner-occupiers are treated as if they were landlords renting to themselves. The resulting rental income covers expenses such as maintenance, property taxes, and mortgage payments, while the residual is recorded as household rental income.

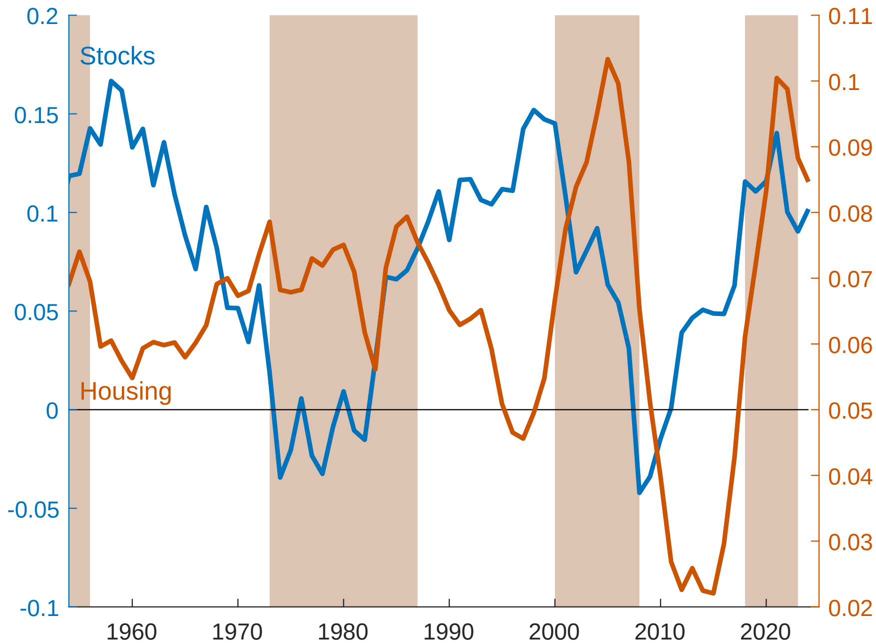

Figure 1: **Returns on stocks and housing.** This figure plots data on real returns for 10-year holding periods on stocks and housing. Data are annual, 1955 to 2024

B. Stylized Facts about Returns and Cashflows

Figure 1 plots the real returns on stocks and housing over 10-year holding periods. The return on stocks in blue is measured along the left vertical axis, while the return on housing in orange is less volatile and measured along the right vertical axis. The shaded areas indicate years with high house prices.

Figure 1 shows that the stock market did well in the 1960s, 1990s, and 2010s. The housing market, in contrast, did well in the 1950s, 1970s, 2000s, and 2020s. There is negative comovement in the returns on the two assets until the GFC, after which the returns comove positively.

To measure the negative comovement, I estimate the stock market beta of housing returns using a two-sided exponential decay. The stock market beta is the slope coefficient from a regression of real 10-year housing returns on a constant and real 10-year stock returns. The decay puts 10% weight on observations five years ago and five years in the future. The orange line in Figure 2 is the estimated housing beta. The housing beta was mostly negative or zero until the GFC, when it became strongly positive. (We will come back to the green line in Figure 2 when we consider borrowing costs and the associated return on levered housing in Section II.)

These facts raise the following question: What is the key difference between stocks and housing? Somewhat surprisingly, the answer is not their cashflow growth rates. Figure 3 compares the real growth rate of stock and housing cashflows. The figure starts earlier than the previous graphs, since the joint cashflow growth data go back to 1930. The cashflow growth of stocks (blue) is again measured along the left vertical axis, while the cashflow growth of housing (orange) is less volatile and is measured along the

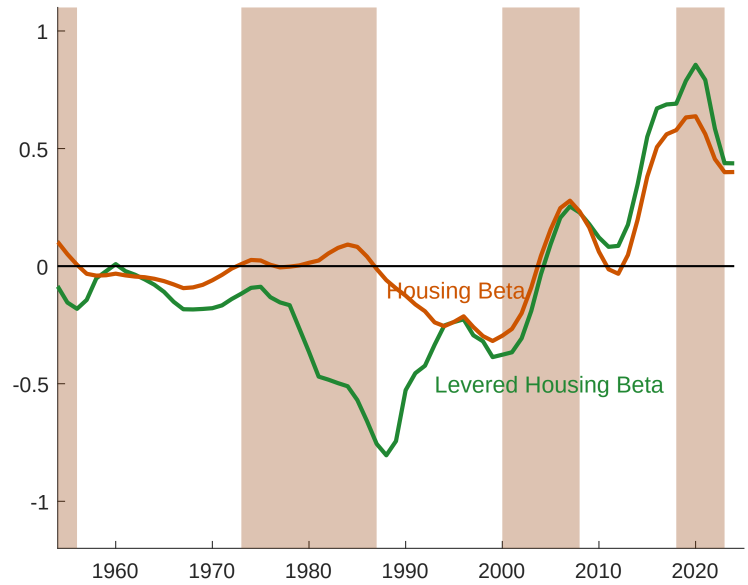

Figure 2: **Housing beta.** The orange line plots the slope coefficient from a regression of 10-year housing returns on a constant and 10-year stock returns. The green line plots the slope coefficient from a regression of 10-year levered housing returns on a constant and 10-year stock returns. The regression captures time-variation in these betas by symmetrically downweighting past and future data with exponential decay (e.g., a 10% weight on observations that are five years from the present.) Data are annual, 1955 to 2024.

right vertical axis. The figure shows strong positive comovement of the two growth rates. The correlation between the two growth rates is 80% for the sample up to the GFC, and somewhat weaker, 59%, for the full sample.

C. *Mechanism for Positive Return Comovements for Similar Cashflows*

To understand the patterns documented in the previous subsection, consider a benchmark model with two Lucas trees, one for stocks and one for housing. Aggregate output Y_t is exogenous with a log growth rate,

$$g_t := \log Y_t - \log Y_{t-1}, \text{ where } g_t \text{ iid} \sim N\left(\mu, \sigma^2\right), \tag{1}$$

where μ is the mean growth rate and σ^2 is its variance.

The two long-lived assets pay cashflows D_t^s and D_t^h in units of numéraire. Total cashflows are $D_t = D_t^s + D_t^h$. Since the exogenous processes for output and cashflows are not stationary in levels, we divide all variables by aggregate output Y_t. The cashflows are $d_t^h = D_t^h / Y_t$ and $d_t^s = D_t^s / Y_t$ as a share of output. There is also a short-lived bond in zero net supply.

The infinitely lived representative agent has utility function

$$\sum_{t=0}^{\infty} \beta^t \log C_t,$$

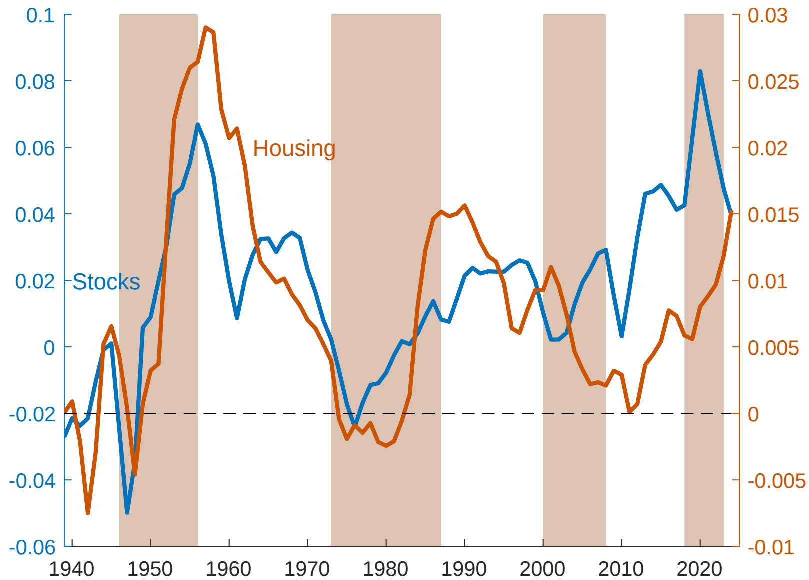

Figure 3: **Cashflow growth of stocks and housing.** This figure plots data on real 10-year cashflow growth of stocks and housing, 1939-2024.

where β represents the discount factor and felicity is log. The agent earns income W_t and holds the trees in equilibrium. In equilibrium, prices adjust so that consumption satisfies $C_t = Y_t = W_t + D_t$, or, written as shares of output, $c_t = w_t + d_t$.

With log utility, we have that optimal consumption and savings are constant fractions of wealth. The price of stocks and housing satisfy the Euler equation

$$P_t^i = E_t\left[\beta\frac{C_t}{C_{t+1}}\left(D_{t+1}^i + P_{t+1}^i\right)\right], \text{ for } i = s, h. \tag{2}$$

We can rewrite this equation using shares of output, $p_t^i = P_t^i / Y_t$,

$$\begin{aligned} p_t^i Y_t &= E_t\left[\beta\frac{C_t}{C_{t+1}}\left(d_{t+1}^i Y_{t+1} + p_{t+1}^i Y_{t+1}\right)\right], \\ &= E_t\left[\beta\frac{C_t}{C_{t+1}}\left(1 + \frac{p_{t+1}^i}{d_{t+1}^i}\right) d_{t+1}^i Y_{t+1}\right]. \end{aligned}$$

Consumption has to grow at the same rate as output and dividends for there to be a stationary solution, so C_t / C_{t+1} and Y_{t+1} / Y_t cancel. The price–dividend ratio becomes

$$\begin{aligned} \frac{p_t^i}{d_t^i} &= E_t\left[\beta\frac{C_t}{C_{t+1}}\left(1 + \frac{p_{t+1}^i}{d_{t+1}^i}\right)\frac{d_{t+1}^i Y_{t+1}}{d_t^i Y_t}\right], \\ v_t^i &= E_t\left[\beta\left(1 + v_{t+1}^i\right)\frac{d_{t+1}^i}{d_t^i}\right]. \end{aligned}$$

If cashflows are a constant share of aggregate output, the price–dividend ratio $v_i = p_t^i / d_t^i$ is constant for both assets.

The return on asset i is defined as

$$\tilde{R}_{t+1}^i = \frac{p_{t+1}^i Y_{t+1} + d_{t+1}^i Y_{t+1}}{p_t^i Y_t} = \frac{\left(\frac{p_{t+1}^i}{d_{t+1}^i} + 1\right) d_{t+1}^i}{\frac{p_t^i}{d_t^i} d_t^i} \frac{Y_{t+1}}{Y_t} = \frac{(v^i + 1)}{v^i} \frac{d_{t+1}^i}{d_t^i} \frac{Y_{t+1}}{Y_t}.$$

Taking logs and assuming that cashflows are a constant share of output implies that log returns are $\tilde{r}_{t+1}^i = 1/v^i + g_{t+1}$, using the approximation that $\log\left((v^i + 1)/v^i\right) = 1/v^i$. Shocks to returns in this model are thus shocks to cashflow growth. Since stocks and housing have the same cashflow growth rate, the model implies that their returns comove perfectly.

Thus, in a standard representative-agent setting, there is positive comovement between returns on two assets with similar cashflows. From the perspective of this model, therefore, the negative comovement in Figure 1 is a puzzle, given the positive comovement of cashflow growth in Figure 3.

The modern asset pricing literature deviates in important ways from the benchmark Lucas tree model described above by including forces that introduce time-variation in discount rates (Cochrane 2011). The economic mechanisms to generate the time variation in discount rates are demographics (Bakshi and Chen 1994, Geanakoplos, Magill, and Quinzii 2004, Favero, Gozluklu, and Tamoni 2011), time-varying volatility in consumption growth (Bansal and Yaron (2004), Bansal et al. 2014), complementarities in the utility function (Yogo 2006, Piazzesi, Schneider, and Tuzel 2007), habit formation (Campbell and Cochrane 1999), learning (Piazzesi and Schneider 2007, Kindermann et al. 2021, Farmer, Nakamura, and Steinsson 2024), or time-varying ambiguity (Epstein and Schneider 2008). The time-variation in discount rates generates *positive comovement* in valuation ratios, since future cashflows are discounted at rates that rise and fall together. As a consequence, time-varying discount rates do not help explain the negative comovement pattern in the data on stock and housing returns, assets with cashflow growth rates that comove positively.

II. Other Differences between Stocks and Housing

If the difference between stocks and housing is not their cashflow growth, what are other differences between the two asset classes?

Liquidity. The first difference is their liquidity. Housing is associated with high transaction costs. Some of these costs are pecuniary, such as commissions to real estate agents and recording fees, and other costs are nonpecuniary, such as the mental costs involved with moving. As a consequence, houses trade rarely with only about 10% of houses trading every year. In contrast, these costs are low in the stock market, and stocks trade often—volume in the stock market is above 100%, which means that every stock trades at least once per year.

Panel A. Home buyers with mortgage and first-time buyers

Panel B. Mortgage payment as a share of income

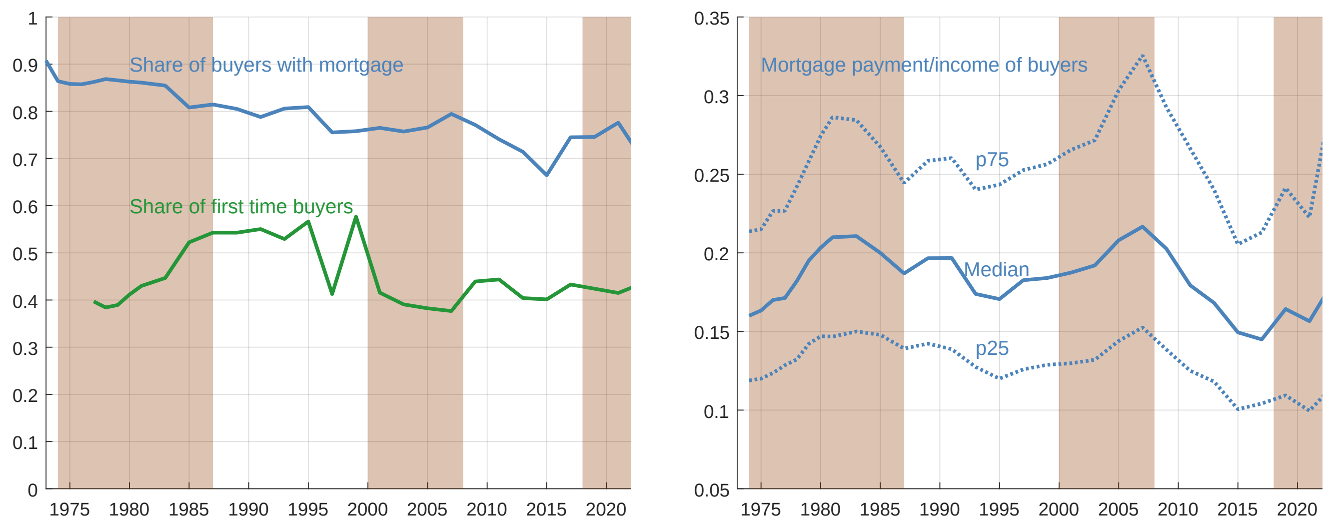

Figure 4: **Leverage in housing transactions**

Infrequent trades translate to, on average, long holding periods for houses. Holding periods have somewhat declined over the last decades. In the American Housing Survey, the average number of years that homeowners have been living in their house was 15.1 in 1980, 15.4 years in 2000, and 11.5 years in 2021. This is the reason I compare real returns on assets over decade-long holding periods.

Finally, infrequent trading also means that each period only a small group of households, who actively trade, matter for house prices. In the language of asset pricing, there are few households on their Euler equations every period, and these few households determine the prices of houses in equilibrium. Most households are passive and do not actively trade. Piazzesi and Schneider (2009) and Landvoigt, Piazzesi, and Schneider (2015) develop models and quantitative approaches to capture this feature.

Leverage. A second key distinction between stocks and housing is the role of leverage. Here, we need to focus on the small group of households that actively trade housing in any given year. Panel A in Figure 4 shows the share of buyers with a mortgage in blue. The vast majority of buyers buy a house with borrowed money. The green line shows the share of first-time buyers. These comprise roughly half of all buyers.

Panel B in Figure 4 shows the share of household income that buyers spend on their mortgage payments. The solid line corresponds to the median, and the dotted lines to the top and bottom quartiles of the distribution. This share is high during the housing booms of the 1970s and 2000s. The share is lower post-GFC, when buyers were, on average, five years older and richer.

Since leverage is important for home buyers, it is important to study how borrowing costs vary over time. Mortgage rates strongly comove with 10-year Treasury rates. Panel A in Figure 5 therefore shows real returns over decade-long holding periods on 10-year Treasuries. The graph shows that borrowing costs are lower during housing booms. They were negative after World War II, in the 1970s, and during the COVID pandemic. Even in the 2000s and 2010s, real borrowing costs were lower than during the previous decade.

The time-variation in borrowing costs raises the question of whether the stylized facts about housing returns carry over to the returns on levered housing. The return on levered housing is the housing return minus borrowing costs. The borrowing costs are multiplied by 80% to reflect the typical down payment. Panel B in Figure 5 shows stock returns and levered housing returns. Both time series are now measured along the left vertical axis, because the levered housing return is volatile. The negative comovement between stock returns and levered housing returns is even stronger. In fact, the beta for levered housing—the green line in Figure 2—is more negative than the beta of the return on unlevered housing prior to the GFC and turns positive after the GFC.

Diversification. A third important difference between stocks and housing investments is diversification. The Sharpe ratio of the overall stock market captures risk-return trade-offs. This is because, since the 1970s, households buy passively managed mutual funds and index funds. While individual stock investments have substantial idiosyncratic risks, these risks get diversified away. For housing, the Sharpe ratio of the overall housing market is not relevant. Households buy a single house, not diversified mutual funds or indices. The location of the house and its other characteristics matter for the average capital gain on an individual house.

To illustrate the importance of location for housing, consider San Francisco, California, and Huntsville, Alabama. The two cities are often compared with each other, because they are both technology and innovation hubs. San Francisco is a center for software and biotech. Huntsville has a strong aerospace, defense, and engineering presence, as well as a growing private tech sector. Both cities have high

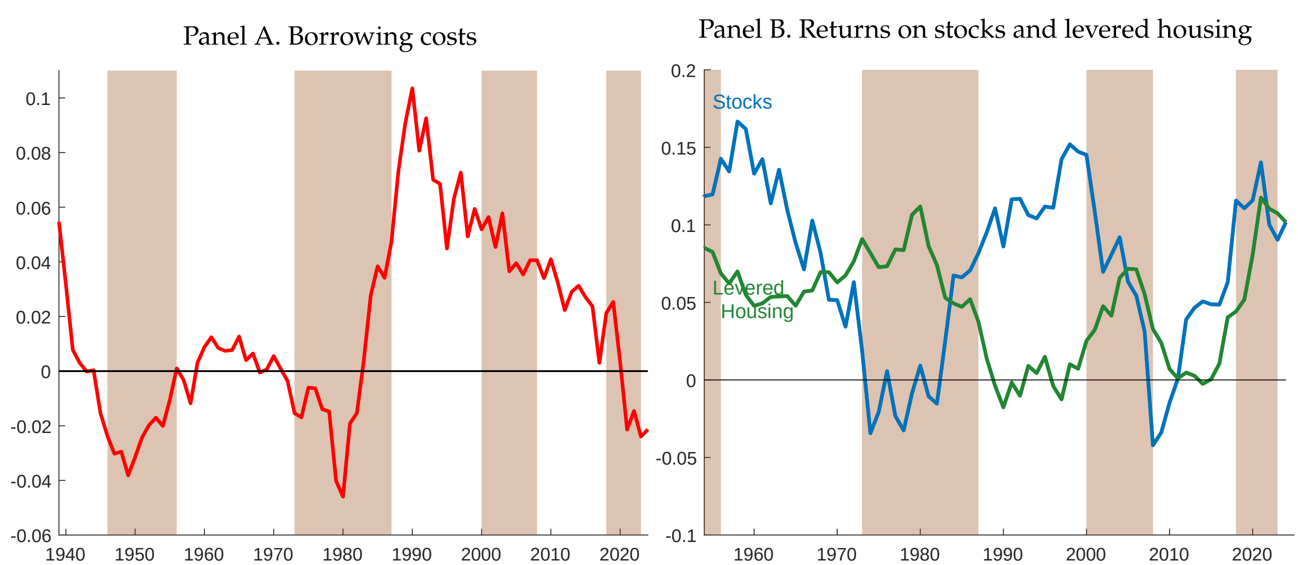

Figure 5: **Accounting for leverage in the returns on housing.**

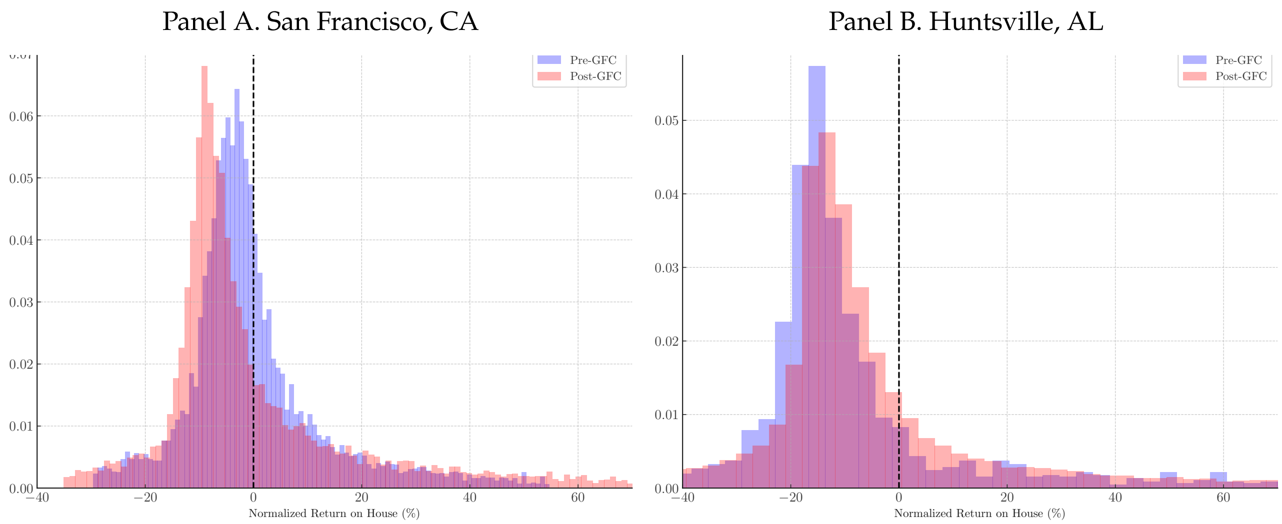

Figure 6: **Histogram of idiosyncratic capital gains on housing over the last decade.**

economic growth and an above average share of workers with college and advanced degrees.

Based on data from CoreLogic, the average capital gain on houses over the last decade was 6.7% per year in San Francisco, while that on houses in Huntsville was 40 basis points. The location-specific average allows me to measure the idiosyncratic component of capital gains on individual houses. By observing repeated transactions of the same house, I can compute the capital gain on the individual house and subtract the location-specific average capital gain over the same holding period.

Panel A in Figure 6 shows the cross-sectional distribution of idiosyncratic capital gains for San Francisco. This is based on CoreLogic data of individual housing transactions. The blue histogram corresponds to transactions before the GFC, and the red histogram to transactions after the GFC. The results show substantial volatility, from −40 to 60% per year. The distribution is right-skewed, more so after the GFC. Panel B in Figure 6 shows a similar histogram for transactions in Huntsville—the volatility is similar, and the distribution is right-skewed, more so after the GFC as in San Francisco.

This evidence suggests that there is a large idiosyncratic component in the volatility of housing returns. This idiosyncratic risk reduces the Sharpe ratio of an investment in a single house relative to the Sharpe ratio for the aggregate housing market. For example, Jordà, Schularick, and Taylor (2019) document a very high Sharpe ratio of one for aggregate housing returns in U.S. postwar data. To achieve such strong performance, a household would have to buy a diversified housing portfolio based on several properties. Early work on idiosyncratic risk in housing returns has used households' self-assessed market values of their own homes from the Panel Study of Income Dynamics (Flavin and Yamashita 2002). More recent work exploits digitized deeds data from providers such as CoreLogic. Transaction-based studies include Landvoigt, Piazzesi, and Schneider (2015) and Giacoletti (2021).

In sum, this section documents three differences between housing and stock investments: liquidity, leverage, and diversification. These features can naturally arise in a segmented-market model with credit.

The next section analyzes such an environment.

III. Segmented Markets with Heterogeneous Households

A. Environment

To analyze the negative comovement between stock and housing returns, I adapt the Lucas tree model from Section I. As in the baseline setup, there are separate Lucas trees for stocks and for housing, and short-term bonds are in zero net supply. All assets have payoffs in units of numéraire consumption. The key modification concerns the agents: the economy contains two types, those who participate in the stock market and those who participate in the housing market. Both types have access to trading in short-term bonds.

There are many agents of the same type. A fraction δ_s of agents can trade in stocks and bonds, while a fraction δ_h of agents can trade in housing and bonds. The two types add up to the total population, $\delta_s + \delta_h = 1$. When young, agents receive income $w_{i,t}Y_t$, where $w_{i,t}$ is the share of income in aggregate output, $i = s, h$. Since agents have no initial assets, this income is also their wealth. The aggregate labor income, or aggregate wealth of young households, as a share of aggregate output is the weighted sum of income shares, $w_t = \delta_s w_{s,t} + \delta_h w_{h,t}$.

For simplicity, I consider an overlapping-generations (OLG) framework in which households live for two periods. Households derive utility only from consumption in old age. Consequently, young households save their entire income $w_{i,t}$ and consume only when old. This model thereby retains constant savings rates, an assumption that helps isolate candidate mechanisms for negative comovement in returns on assets with similar cashflows.

This is a minimal setup, which combines segmented markets for stocks and housing with heterogeneous households of type $i = s, h$ who trade type-specific assets with other households of the same type. In the OLG framework, young households buy their type-specific asset from old households of the same type. When old, these same households sell their asset holdings to the next generation of the same type.

However, the markets for stocks and housing are still connected through credit markets. Since households live for two periods, the old households cannot borrow (because they cannot repay their loan in the future). They will also choose not to lend, because they do not care about consumption in the future. Thus, while Lucas trees trade among households of the same type across generations, bonds trade among young households of different types.

Complete market segmentation is, of course, a stark assumption. In practice, many stockholders also own houses, but these houses tend to be concentrated in the luxury segment of the housing distribution. Such properties can be viewed either as a negligible fraction of the total stock or a distinct asset class.[3]

[3] An open question is whether prices of luxury homes covary more closely with the stock market than other housing. Aït-Sahalia, Parker, and Yogo (2004) provide supportive evidence.

Moreover, middle-class households save for retirement and therefore increasingly hold stocks through mutual funds. Given the substantial wealth inequality in the United States, however, most of the stock market is held by wealthy stockholders.

Market segmentation captures *benefits of ownership* familiar from housing models: homebuyers receive dividends from their houses that nonowners cannot claim. In the setup here, households of type s cannot trade housing. This assumption is *as if* households s do not receive or value dividends from housing and therefore decide not to consider the asset. Conversely, segmentation captures nonparticipation in the stock market by households that lack the financial sophistication to value stock dividends. Households of type h may nevertheless value the dividends from housing, perhaps because previous generations in the family held this asset type and educated younger generations about its benefits.

We can think of households of type s as participants in the stock market, broadly speaking. These households either actively trade or passively own stocks. Households of type h represent the small group of homebuyers that actively trade houses and therefore determine house prices. In Panel A of Figure 4 above, we saw that the vast majority of homebuyers borrow money to buy their house. We could consider a simple extension of the model with a third household type. This type would capture the majority of homeowners who passively own their house and do not trade. This agent type would not matter for the determination of equilibrium house prices, but could, for example, invest in bonds to capture the portfolios of older households. I do not pursue this extension here.

Household problem. Each household solves the following problem:

$$\begin{gathered}\max E\left[\log c_{i,t+1}\right] \\ p_{i,t}\theta_{i,t} + b_{i,t} = w_{i,t}, \\ c_{i,t+1} = \left(p_{i,t+1} + d_{i,t+1}\right)\theta_{i,t} + b_{i,t}R, \\ \phi p_{i,t+1}\theta_{i,t} \geq -Rb_{i,t}.\end{gathered} \tag{3}$$

Households of type i trade the Lucas tree on the market they have access to at price $p_{i,t}$ and also trade bonds $b_{i,t}$, both written as shares of aggregate output, and consume their payoffs at $t+1$. These payoffs consist of interest on positive holdings of the bonds ($b_{i,t} > 0$) or repayment of the loan ($b_{i,t} < 0$), as well as dividends plus the proceeds $p_{i,t+1}$ from selling holdings $\theta_{i,t}$ of the Lucas tree to the next generation of households of type i. If households make a leveraged Lucas tree purchase, whereby they borrow at date t to buy shares of the Lucas tree, they can use part or all of the proceeds from their tree sale at $t+1$ to repay their loan.

The inequality in the last line of the household problem (3) describes a collateral constraint. The constraint ensures that the loan repayment is smaller than a fraction $\phi > 0$ of the price of the Lucas tree. Here, the constraint is based on a fraction of the *future* price of the Lucas tree. The constrained credit demand $b_{i,t} = -\phi p_{i,t+1}\theta_{i,t}/R$ then depends directly on the interest rate R.[4] The amount $p_{i,t+1}\theta_{i,t+1}(1-\phi)$

[4]When the constraint is based on a fraction of the current price of the Lucas tree, $-b_{i,t} \leq \phi p_{i,t}\theta_{i,t}$, credit demand does not depend directly on the interest rate.

is the down payment required for the loan. We can also interpret $1-\phi$ as a haircut, the difference between the value of the Lucas tree and the collateral value, measured at $t+1$.

The analysis of the household problem is easier in terms of portfolio weights $\alpha_{i,t} = p_{i,t}\theta_{i,t}/w_{i,t}$ invested in the Lucas tree. From the budget equation for date t, the portfolio weight on bonds is $1-\alpha_{i,t}$. Solving for $\theta_{i,t} = \alpha_{i,t}w_{i,t}/p_{i,t}$ and inserting the expression into the budget constraint for $t+1$, we can rewrite the household problem as

$$\max_{\alpha_{i,t} \leq R/(R-\phi)} E_t \left[\log \tilde{R}^i_{t+1}\alpha_{i,t} + R\left(1-\alpha_{i,t}\right) \right]. \tag{4}$$

The log returns $\tilde{r}^i_{t+1} = \log \tilde{R}^i_{t+1}$ are normally distributed with mean $1/v^i + \mu$ (ignoring a Jensen's inequality term). Under this distributional assumption, Campbell and Viceira (1999) derive the Merton weight as an approximate solution to the portfolio choice problem with a log objective in discrete time. The household may not be able to achieve the Merton weight if the collateral constraint binds, in which case the portfolio weight has to be lower. The optimal portfolio weight is therefore

$$\alpha_{i,t} \approx \min\left\{ \frac{\frac{1}{v_i} + \mu - r}{\sigma^2}, \frac{R}{R-\phi} \right\}. \tag{5}$$

The demand for Lucas tree i scales this portfolio weight by the savings of group i, $\delta_i w_{i,t}$. If the collateral constraint does not bind, *bad news about the economy*, defined as lower expected growth μ or higher uncertainty σ^2, will lower the demand $\alpha_{i,t}\delta_i w_{i,t}$ for the Lucas tree. If the collateral constraint binds, the asset demand is not sensitive to bad news about the economy.

Equilibrium with segmented markets. In equilibrium, households solve their problem (3) given asset prices $p_{s,t}$, $p_{h,t}$, and R_t, and markets clear. The market-clearing conditions for the Lucas trees are $\delta_i\theta_{i,t} = 1$, $i = s, h$. For bond market clearing, we need $\delta_s b_{s,t} + \delta_h b_{h,t} = 0$. The goods market clears when $\delta_s c_{s,t} + \delta_h c_{h,t} = w_t + d_{s,t} + d_{h,t}$.

The goal is to characterize properties of steady states in which price–dividend ratios are constant. I therefore assume that all shares of aggregate output, such as cashflows and labor income, are constant. The market-clearing condition for Lucas trees implies that each household holds a share $1/\delta_i$ of their type-specific Lucas tree in equilibrium. With one Lucas tree worth p_i, we can also express the value of the tree supply as $p_i = v_i d_i$. The market-clearing condition thus implies that the portfolio share equals $\alpha_i = p_i\theta_i/w_i = v_i d_i/(\delta_i w_i)$. The portfolio share is larger (smaller) than one if agent type i borrows (lends). For the credit market, the market-clearing equation is $\delta_h b_h + \delta_s b_s = 0$. This equation implies that the borrowing of one agent type equals the lending of the other type. By summing the budget equations of young households across types and using credit market clearing, we get that the value of the Lucas trees equals total savings, $v_s d_s + v_h d_h = w$.

Since households save their entire income and only households of type $i = s, h$ can buy Lucas trees of type i, we can sum the budget equations of young households of type i and obtain that the total value of their asset holdings equals their total income:

$$v_i d_i + \delta_i b_i = \delta_i w_i. \tag{6}$$

The model is entirely symmetric. Without gains from trade, we would expect to see no credit, $\delta_i b_i = 0$, in equilibrium. Under certain conditions on parameter values, which we analyze below, there will be gains from trade in the credit market. For now, I use the convention that *total credit* in the economy refers to bond holdings of a particular type of households, namely, stockholders: $Q = \delta_s b_s$. This convention is arbitrary at the moment, so that total credit can be zero, positive, or negative, $Q \gtreqless 0$.

By combining the market-clearing condition for Lucas tree i with the optimal unconstrained portfolio share of the respective investors in that tree, we obtain the *Gordon Growth formula* for the price–dividend ratio,

$$v_i = \frac{1}{r - \mu + \sigma^2 \alpha_i}, \tag{7}$$

where μ is expected cashflow growth and $\sigma^2 \alpha_i$ is the *risk premium* of Lucas tree i, given by the covariance of the return on the tree with the consumption growth of its investors, which are households of type i.

First, we evaluate the Gordon Growth formula for stocks and solve for the interest rate, using the expression $v_s = \delta_s (w_s - b_s)/d_s$ for the price–dividend ratio from equation (6) together with the definition of total credit, $Q = \delta_s b_s$. We obtain the *credit supply function*

$$r_s(Q) = \frac{d_s}{\delta_s w_s - Q} + \mu - \sigma^2 \frac{\delta_s w_s - Q}{\delta_s w_s}, \tag{8}$$

where the notation emphasizes that the interest rate is a function of credit supply. The ratio in the last term is just the aggregate portfolio share invested in stocks in equilibrium, computed for investors who can invest in this Lucas tree. Figure 7 shows the upward-sloping curve in a graph with the interest rate r on the vertical axis and total credit Q on the horizontal axis. To supply more credit, stockholders require a higher interest rate. The credit supply curve has a vertical asymptote at $Q = \delta_s w_s$, the point at which all stockholder savings are lent out as credit. For stockholders to lend out so much of their savings, they charge an ever-higher interest rate that goes to infinity in the limit.

Next, we evaluate the Gordon Growth formula for housing, again using $v_h = \delta_h (w_h - b_h)/d_h$ from equation (6) together with credit market clearing $\delta_s b_s + \delta_h b_h = 0$, so $-\delta_h b_h = Q$. We get the *credit demand function*

$$r_h(Q) = \frac{d_h}{\delta_h w_h + Q} + \mu - \sigma^2 \frac{\delta_h w_h + Q}{\delta_h w_h}, \tag{9}$$

where the notation again emphasizes that the interest rate is a function of credit demand. The subscript h on the interest rate is a reminder that credit demand is derived from the Gordon Growth formula for housing. Figure 7 shows the downward-sloping solid curve in a graph with the interest rate r on the vertical axis and total credit Q on the horizontal axis. Homebuyers have a demand for credit, which declines with interest rates. The function has an asymptote at $Q = -\delta_h w_h$, the point at which stockholders

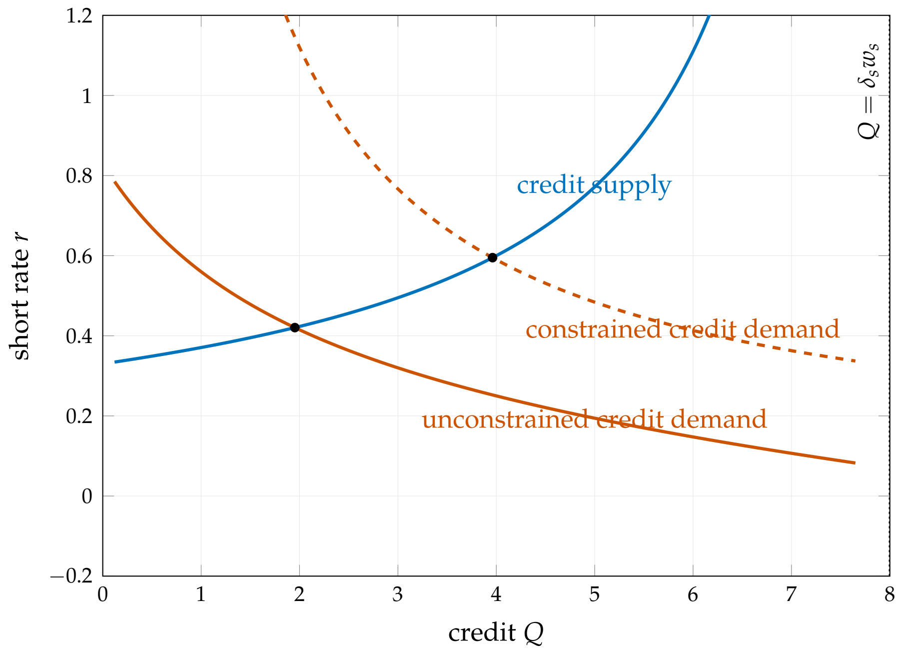

Figure 7: **Credit market equilibrium.**

borrow the entire savings of homebuyers.

The equilibrium is the intersection of credit demand and supply, $r_s(Q^*) = r_h(Q^*)$. We can define the excess demand function as the difference between demand (9) and supply, (8)

$$f(Q) = r_h(Q) - r_s(Q). \tag{10}$$

The function is strictly decreasing on $(-\delta_h w_h, \delta_s w_s)$ with $\lim_{Q\downarrow -\delta_h w_h} f(Q) = \infty$ and $\lim_{Q\uparrow \delta_s w_s} f(Q) = -\infty$, as shown in Appendix A. By continuity and the intermediate value theorem, together with monotonicity, we have the existence of a unique equilibrium.

If the collateral constraint binds, we can solve the constrained portfolio weight $\alpha_h = v_h d_h / (\delta_h w_h) = R/(R - \phi)$ for the interest rate $r = R - 1$, again using equation (6) together with credit market clearing to substitute for the value of housing, $v_h d_h = \delta_h w_h + Q$. The credit demand function (9) is then replaced by

$$r_h(Q) = \phi \frac{\delta_h w_h + Q}{Q} - 1, \tag{11}$$

another downward-sloping dashed curve in Figure 7. As credit goes to zero, the required short rate that keeps constrained homebuyers at their borrowing limit explodes. The excess demand function $f(Q)$ in equation (10) based on the constrained credit demand curve is strictly decreasing on $(0, \delta_s w_s)$ with $\lim_{Q\downarrow 0} f(Q) = \infty$ and $\lim_{Q\uparrow \delta_s w_s} f(Q) = -\infty$. Again, we have the existence of a unique equilibrium.

No-credit benchmark. To gain intuition for how the model works, it helps to examine a situation without credit between the households. Without credit, stockholder savings equal the value of all stocks, $v_s d_s = \delta_s w_s < w$. Similarly, homebuyer savings equal the value of all housing, $v_h d_h = \delta_h w_h$. The portfolio share $\alpha_i = v_i d_i / \delta_i w_i$ of households of type i on their Lucas tree equals one. As a consequence, the risk premium in the Gordon Growth formula reduces to σ^2. Since the function $f(Q)$ has to be zero at $Q = 0$ for the no-credit benchmark to be an equilibrium, the interest rate has to satisfy $r = d_i/(\delta_i w_i) + \mu - \sigma^2$. For this equation to hold for both types, $i = s, h$, we need that the ratio $\delta_i w_i / d_i$ of type-i household savings to the future cashflows from their Lucas tree is the same across both types of households.

In the no-credit benchmark, we are back to a model that works like the representative-agent model. Households of type i determine the pricing of their Lucas tree. The price–dividend ratio on both trees is constant, as in the representative agent case. The price–dividend ratio equals the amount of savings that buy the tree divided by its dividend, $v_i = \delta_i w_i / d_i$. The (log) returns $\tilde{r}^i_{t+1} = 1/v_i + g_{t+1}$ on the two Lucas trees comove positively as in the representative-agent case, because the shocks to cashflow growth rates are the same across the two trees.

Collateralized credit. Thus far, everything is symmetric for stocks and housing. What could be the gains from trade in the credit market between the two agents? The next assumption states that homebuyer savings per unit of the cashflows of their Lucas tree are lower than stockholder savings per unit of their cashflows.

ASSUMPTION A. *Homebuyers have lower savings per unit of cashflows than stockholders, $\delta_h w_h / d_h < \delta_s w_s / d_s$.*

Since households save all of their income for future consumption, the assumption is about exogenous variables: incomes w_i and cashflows d_i. The assumption describes a world in which homebuyers are poorer than stockholders relative to the future cashflows of the assets they want to buy. In the data, the wealthiest households in the U.S. economy are indeed stockholders, while homeowners constitute the middle class. I also emphasize that to derive the no-credit benchmark, we assume that $\delta_i w_i / d_i$ are the same across agent types i, which violates Assumption A. The next proposition shows that if homebuyers are poorer than stockholders in the sense of Assumption A, homebuyers borrow using their houses as collateral.

PROPOSITION 1. *If Assumption A is satisfied, homebuyers borrow from stockholders.*

Proposition 1 states that if homebuyers are poorer per unit of their future cashflows than stockholders, they borrow from stockholders in equilibrium. The credit market thus enables poorer households to buy houses with the savings of stockholders, using their house as collateral and repaying the loan later, when they have more resources.

If Assumption A is satisfied, the excess demand for credit is negative, $f(0) > 0$, when evaluated at the no-credit benchmark, $Q = 0$. The function $f(Q)$ is strictly decreasing in Q, so the equilibrium under Assumption A must involve more credit $Q^* > 0$ than in the no-credit benchmark. In equilibrium, the price–dividend ratio for stocks $v_s^* = (\delta_s w_s - Q^*)/d_s$ is now lower, while the price–dividend ratio for housing $v_h^* = (\delta_h w_h + Q^*)/d_h$ is higher than in the no-credit benchmark.

Of course, in the absence of Assumption A, the model is otherwise symmetric. We could make homebuyers richer than stockholders per unit of future cashflows from their Lucas tree, thereby reversing the inequality in Assumption A, and obtain the opposite result of Proposition 1. In this case, homebuyers would lend to stockholders. However, the data suggest that the vast majority of homebuyers have a levered position in their house, while stockholders do not use leverage to buy their stocks.

Channels for negative housing betas. Since cashflow growth rates for stocks and housing are similar, negative housing betas must result from opposite movements in the price–dividend ratios of stocks, v_s, and housing, v_h. In the model, the price–dividend ratio for housing satisfies $v_h = (w - v_s d_s)/d_h$, where aggregate income w as well as cashflows d_h and d_s are exogenous. Any shifter θ in the price–dividend ratio for stocks, $\delta v_s/\delta\theta$, will therefore push v_h in the opposite direction in this model, $\delta v_h/\delta\theta = -(d_s/d_h)\,\delta v_s/\delta\theta$. The effect is multiplied by the ratio of stock dividends to housing dividends.

The next proposition characterizes a *credit market channel* that generates negative return comovement. In response to bad news about the aggregate economy, flight to safety by stockholders increases the credit supply to constrained homebuyers at lower interest rates, leading to higher house prices and lower stock prices (part ii of Proposition 2). When homebuyers are unconstrained, credit demand and interest rates fall, leading to lower house prices and higher stock prices (part i of Proposition 2.) In both cases, we see negative comovement.

PROPOSITION 2. *Suppose Assumption A holds.*
i. Suppose the collateral constraint does not bind for homebuyers. Lower mean growth μ lowers the interest rate and leaves price–dividend ratios and credit unchanged. Higher uncertainty σ^2 increases the price–dividend ratio v_s for stocks, lowers the price–dividend ratio v_h for housing, lowers credit, and lowers the interest rate.
ii. Suppose the collateral constraint binds for homebuyers. Bad news about the economy, defined as lower mean growth μ or higher uncertainty σ^2, lowers the price–dividend ratio v_s for stocks, increases the price–dividend ratio v_h for housing, increases credit, and lowers the Interest rate.

To understand the two parts of Proposition 2, we start by examining the unconstrained credit demand $r_h(Q)$. When excess demand $f(Q) = r_h(Q) - r_s(Q)$ is based on equation (9), it does not depend on expected growth because the same expected cashflow growth μ enters both credit demand and supply additively. As both demand and supply curves in Figure 7 shift down by μ, the intersection of the curves stays at the same level of credit Q^*, but with an interest rate that is lower by μ. With v_s^* unchanged, the housing price–dividend ratio v_h^* also does not change. Moreover, credit, $Q^* = \delta_s w_s - v_s^* d_s$, is unaffected since v_s^* does not change.

Higher uncertainty σ^2 also shifts down both credit demand and credit supply in Figure 7 but to different degrees. The reason is that the shift depends on the portfolio weights of the borrower α_h and the lender α_s, respectively. The derivative $\delta f(Q)/\delta\sigma^2 = -(\alpha_h - \alpha_s)$, computed in Appendix B and displayed in equation (B1), equals the difference in portfolio weights. Under Assumption A, we know from Proposition 1 that homebuyers borrow from stockholders, which implies that they have a higher portfolio weight on their Lucas tree and therefore the derivative is negative. Intuitively, when home purchases are levered, the credit demand by homebuyers is more sensitive to a shift in uncertainty than the credit supply by stockholders, who are not leveraged. When credit demand shifts down more than credit supply in Figure 7, credit, the interest rate, and the price–dividend ratio for housing fall, while the price–dividend ratio for stocks increases. Appendix B provides the formal argument using the implicit function theorem.

Constrained credit demand in equation (11) is unaffected by bad news about the economy. In Figure 7, only credit supply shifts down with lower expected growth μ. Excess credit supply $f(Q)$ based on constrained credit demand increases with lower expected growth, since $\partial f(Q)/\partial\mu = -1$. When credit supply shifts down in Figure 7, credit and the price–dividend ratio for housing increase, while the interest rate and the price–dividend ratio for stocks fall. An increase in σ^2 again only shifts credit supply down. In this case, $\delta f(Q)/\delta\sigma^2 = \alpha_s$, as displayed in equation (B2). Again, the equilibrium moves down and right with the same effects as in the case of lower expected growth.

Part i of Proposition 2 describes a *credit demand channel* for negative comovement. If homebuyers are unconstrained and poorer today relative to their future dividends, they borrow from stockholders to finance housing purchases. This borrowing implies a Merton portfolio weight on housing (4) greater than one. Stockholders, by contrast, lend and thus have a positive bond position in their portfolio, leaving their portfolio weight on stocks lower than one. As a consequence, homebuyers are more sensitive to changes in uncertainty than stockholders. An increase in uncertainty leads homebuyers to sharply reduce their credit demand, while stockholders adjust their credit supply only modestly. The outcome is a contraction in credit and a decrease in the equilibrium interest rate and housing prices. At the same time, stockholders reallocate away from more expensive bonds into equities, raising stock prices. When growth expectations decline, the interest rate falls as well, but the lower discount rate exactly offsets the weaker expected cashflow growth. Price–dividend ratios and credit, therefore, remain unchanged.

In contrast, part ii of Proposition 2 describes a *credit supply channel*. When homebuyers are constrained, their credit demand is pinned at the limit and unresponsive to news about the economy. Stockholders, however, adjust sharply—bad news reduces the attractiveness of stocks relative to bonds, because either expected cashflow growth falls or uncertainty rises. In response, stockholders increase credit supply, which lowers the interest rate and the stock price–dividend ratio. The decline in rates enables constrained homebuyers to borrow more, thereby raising credit in equilibrium. The resulting increase in housing demand pushes up the housing price–dividend ratio.

An important feature of Proposition 2 is that the news is bad about the *whole economy*. The news is about the mean μ and the variance σ^2 of the aggregate growth rate g_t in equation (1). We could have also obtained negative comovement in the price–dividend ratios of stocks and housing in response to asset-specific news. If cashflows of stocks and housing had their own growth rates g_t^i, for $i = s, h$, with asset-specific mean μ_i and variance σ_i^2, it would be easy to generate negative comovement with negatively correlated news about the two assets. However, we are looking for a channel for negative comovement that applies to assets with *similar cashflows*. This makes asset-specific news less plausible as a driving force.

Examples of bad news for negative housing betas include the increases in house prices during the Great Inflation in 1970s (Leombroni et al. 2020), dotcom companies missing earnings expectations in 2000 (Ľuboš Pástor and Veronesi 2006, the COVID pandemic (Gormsen and Koijen 2020, Cox, Greenwald, and Ludvigson 2020) and the post-pandemic inflation in 2020-22 (which coincided with the increased tendency to work more from home, as studied by Mondragon and Wieland 2022 and Richard 2024).

B. Discussion

Alternative sources of gains from trade in credit markets. In the simple benchmark model, homebuyers are poorer today relative to their future dividends than stockholders and therefore borrow from stockholders. There are, however, additional reasons for gains from trade in credit markets.

First, gains from trade can arise from aggregate risk-sharing. As shown in Figure 3, data on the cashflow growth of housing is less volatile than the cashflow growth of stocks. Since both series move cyclically in similar ways, housing appears less exposed to aggregate risk than stocks. If we incorporated this feature in the model by assuming that housing cashflow growth is less exposed to aggregate output growth shocks, the model would again generate gains from trade, with homebuyers borrowing from stockholders.

Second, gains from trade arise when idiosyncratic risk is diversified. As illustrated in Figure 6, data on housing returns contain a substantial amount of idiosyncratic risk. In a model with only nondefaultable bonds, idiosyncratic risk discourages borrowing by homebuyers. By extending the model to defaultable bonds, homebuyers could borrow from stockholders who would then effectively invest in a diversified pool of defaultable bonds.

Additional single-market channels. To assess these mechanisms quantitatively, it is helpful to consider additional forces that may operate within a single market. A well-studied example is the dramatic expansion of credit and the nationwide housing boom of the early 2000s. One strand of the literature emphasizes laxer collateral requirements as a key driver. For example, Iacoviello (2005), Landvoigt, Piazzesi, and Schneider (2015), Favilukis, Ludvigson, and Nieuwerburgh (2017), Garriga and Hedlund (2020), and Greenwald and Guren (2025)) investigate the quantitative implications of lower down payment constraints on house prices.

Another strand of the literature highlights exuberance—not necessarily widespread optimism, but optimism concentrated among homebuyers—as an indispensable ingredient without which the scale of the boom would be hard to reconcile. For example, Case and Shiller (2003), Piazzesi and Schneider (2009), Geanakoplos (2010), Case, Shiller, and Thompson (2012), Landvoigt (2017),Burnside, Eichenbaum, and Rebelo (2016), Bailey et al. (2019), Kaplan, Mitman, and Violante (2020), Chodorow-Reich, Guren, and McQuade (2024)) document high house price expectations and study their quantitative impact on house prices (for a survey of expectations about housing more generally, see Kuchler, Piazzesi, and Stroebel (2023)).

In the benchmark segmented-markets model, both of these forces—laxer collateral requirements and buyer optimism— activate the *credit demand channel* of Proposition 2i, but with the opposite sign: both forces expand credit demand and in turn house prices, pushing up interest rates since savings are stable. Consistent with this mechanism, Figure 1 shows negative comovement in the early 2000s: housing returns rose while stock returns declined.

While these forces are well documented and were certainly all at work, interest rates did not rise during the 2000s boom. This is why a *credit supply shifter* is also needed to explain this episode. The literature points to several causes for such shifters. Empirical papers document reduced lending frictions, for example, from financial innovation coupled with deregulation in the securitization of subprime mortgages (e.g., the securitization of subprime mortgages in Mian and Sufi 2009, Keys et al. 2010, optimistic lender beliefs (Adelino, Schoar, and Severino 2018), or higher government subsidies (Lucas and McDonald 2010). Other papers similarly study the impact of a reduction in financial frictions on house prices in quantitative housing models (e.g., Justiniano, Primiceri, and Tambalotti 2019, Leombroni et al. 2020).

Housing as an inflation hedge. During periods of high surprise inflation, levered housing positions perform particularly well because inflation erodes the real value of mortgage debt. During the postwar period, the United States has experienced two episodes with particularly high inflation: the Great Inflation of the 1970s (studied by Leombroni et al. 2020) and the post-pandemic inflation of 2021 to 22. Both episodes involved negative return comovement—housing booms coinciding with a stock price slump.

Many countries experienced strong consumer price inflation during the 1970s, following the 1973 to 74 OPEC oil embargo and the 1979 Iranian Revolution. Piazzesi and Schneider (2008) provide evidence from 12 OECD countries. Their Figure 12 shows, for each country, the price–dividend ratios for stocks and housing in the upper panel, together with inflation and the real interest rate in the lower panel. Across these 12 countries, the 1970s were characterized by high inflation, a housing boom, and a stock market slump. In the United States, increased government intervention in the mortgage market—such as the establishment of the mortgage underwriting programs by Fannie Mae and Freddie Mac in the 1970s—may have amplified the housing boom. However, the rise in housing price–dividend ratios during the high inflation of the 1970s was a broad international phenomenon, spanning countries with widely different degrees of government involvement in mortgage markets. A striking parallel arises with the post-pandemic inflation episode of 2021 to 2022, which brought the sharpest consumer price increases since the 1970s and likewise a housing boom and stock market slump. In contrast, during 2023 to 2024 house prices declined while stock prices recovered.

Time-variation in bond betas. A growing literature documents and analyzes time-variation in the bond beta. The evidence shows that the bond beta was positive before 1998, turned negative, and reverted to positive after 2021 (e.g., Connolly, Stivers, and Sun 2005, Guidolin and Timmermann 2006, Baele, Bekaert, and Inghelbrecht 2010, Campbell, Sunderam, and Viceira 2017, Campbell, Pflueger, and Viceira 2020, Chernov, Lochstoer, and Song 2021, Cochrane 2024, Pflueger 2025, Marciano 2025). This literature focuses on stock and bond markets in isolation. To date, no work considers the spillovers of bond betas to housing markets. Yet, because bond betas reflect borrowing costs, they can naturally amplify negative housing betas, as illustrated in Figure 2.

C. *Positive Comovement after the GFC*

The following proposition characterizes forces that weaken credit market channels that generate negative comovement in returns.

PROPOSITION 3:
i. If $\delta_h w_h / d_h = \delta_s w_s / d_s$, there is no more credit. Bad news about the economy does not affect price–dividend ratios but still lowers the interest rate.
ii. Scaling household savings by $\lambda > 1$ increases both price–dividend ratios.
iii. Discount rate changes (e.g., induced by population growth) move price–dividend ratios together.

For part i, we study the excess credit demand, $f(Q) = r_h(Q) - r_s(Q)$, based on unconstrained credit demand (9). Without credit, $Q = 0$, excess credit demand reduces to $f(0) = d_h/(\delta_h w_h) - d_s/(\delta_s w_s)$. Together with identical ratios of incomes to cashflows across agents, as assumed in part i of Proposition 3, we have $f(0) = 0$, ensuring a no-credit equilibrium. Excess credit demand is independent of expected growth μ and uncertainty σ^2, so bad news does not affect credit or price–dividend ratios of the Lucas trees. The interest rate, however, satisfies $r = 1/v + \mu - \sigma^2$ and therefore declines when bad news arrives.[5]

For part ii, suppose that we scale income per person by $\lambda > 1$. Appendix C uses the implicit function theorem to show that the price–dividend ratios of stocks and housing both increase in response to this scaling. Higher income and thus higher savings by stockholders and homebuyers push up the prices of the assets they trade.

For part iii, we allow for population growth. In the benchmark segmented-markets model, the shares of stockholders and homebuyers sum to one, $\delta_s + \delta_h = 1$. Now suppose instead that $\delta_s + \delta_h = N$, where $N = \exp(nt)$ grows over time at rate n. In this version of the model, a growing number of stockholders and homebuyers compete for a fixed number of Lucas trees. If we assume that incomes w_s and w_h per person also stay fixed, a growing amount of savings is spent on these Lucas trees. Rather than scaling up income per person as in part ii of Proposition 3, this version scales up people per income and otherwise behaves in exactly the same way. Population growth n reduces the effective discount rate $r - n + \sigma^2 \alpha_i$ applied to future cashflows and thereby raises both price–dividend ratios.

These forces shed light on the positive comovement of stock and housing returns after the GFC. The

[5] Interestingly, a local increase in homebuyers' income does not necessarily reduce their borrowing and thus credit in equilibrium. Appendix D shows that credit decreases in response to higher $\delta_h w_h$ for plausible parameter values in the unconstrained case. In particular, the variance σ^2 of the aggregate growth rate needs to be smaller than the share of housing services d_h in GDP. This condition is satisfied in U.S. data. In the constrained case, credit locally *increases*. The global result is that under Assumption A, we know from Proposition 1 that homebuyers borrow from stockholders, and when the two ratios of incomes per cashflows are equal across agents, as assumed in part i of Proposition 3, homebuyers stop borrowing and there is no credit.

negative comovement worked through a credit market channel, which shuts down when homebuyers have more savings. Higher overall savings and discount rate changes generate positive comovements in price–dividend ratios. As discussed in Section II, since the GFC homebuyers have been richer and older. Moreover, in recent years, the share of household income that buyers spend on their mortgage payments has declined. Higher savings by stockholders have also contributed to higher stock market valuations.[6]

Demographics, institutional and foreign investors. A natural candidate explanation for these developments is demographics. Longer lifespans, together with declining fertility rates, have shifted the population's age structure toward a larger share of older households who have accumulated more savings in the past and thus rely less on mortgage credit to purchase homes. Another explanation is the growing presence of institutional and foreign investors in housing markets since the GFC, channeling stockholder savings directly into real estate. Less credit and less segmentation together imply that the price–dividend ratios of stocks and housing comove positively, as they would in a representative-agent model.

There is already some influential work on these mechanisms. Mankiw and Weil (1989) famously argue that the surge in housing demand during the 1970s and 1980s was driven by the Baby Boom generation reaching home-buying age, and predicted a subsequent decline in house prices during the 1990s and 2000s. Other papers that connect slow-changing demographics, the increase in aggregate savings in an aging society, interest rates, and other asset prices are Poterba (2001), Abel (2001), Poterba (2004), Geanakoplos, Magill, and Quinzii (2004), Krueger and Ludwig (2007), Carvalho, Ferrero, and Nechio (2016), Leombroni et al. (2020), Eggertsson, Mehrotra, and Robbins (2021), and Auclert et al. (2021).

Institutional investors, including private equity funds and REITs, entered the single-family rental market in scale, buying foreclosed homes at steep discounts after the GFC. While still a small share nationally, in some metropolitan areas (e.g., Atlanta, Phoenix, Las Vegas) institutional investors became dominant in certain ZIP codes. An active literature is investigating the trading and impact of these investors on house prices (Garriga, Gete, and Tsouderou 2023,Hanson (2024),Raymond 2025,Gorback, Qian, and Zhu (2025)), market liquidity (Buchak et al. 2020), distributional consequences and eviction patterns in rental markets (Raymond et al. 2016, Immergluck and Raymond 2018).

Foreign investors increased their Treasury bond purchases in the early 2000s (Doepke and Schneider 2006). In a famous speech, Bernanke (2005) argued that the decrease in long-term interest rates during this time was not a domestic phenomenon, but rather the result of a global saving glut—an excess of desired saving relative to desired investment abroad, especially in emerging markets. This glut was channeled into U.S. Treasuries and other safe dollar assets, pushing down long rates. Papers that study this phenomenon include Caballero, Farhi, and Gourinchas (2008), Warnock and Warnock (2009), and Favilukis, Ludvigson, and Nieuwerburgh (2017). After the GFC, there has been an increase in foreign purchases of houses in the United States (Gorback and Keys 2020, Li, Shen, and Zhang 2024) as well as the

[6] Proposition 3 also has interesting implications for the cross section of locations. We should see higher price–dividend ratios for housing in locations with richer households. Moreover, we should see stronger comovement with stock price–dividend ratios in these locations. These represent potential avenues for future research.

UK (Badarinza and Ramadorai 2019) and Canada (Favilukis and Nieuwerburgh 2021). More generally speaking, Badarinza and Ramadorai (2025) argue that while housing markets have been analyzed with largely domestic factors only, an international perspective is needed.

IV. Conclusion

This paper documents some new facts about returns and cashflows on broad asset classes. Before the GFC, housing betas are negative, and are more pronounced for levered housing, while stocks and housing have similar cashflow growth rates. After the GFC, housing betas are positive and again lower during the pandemic inflation episode. A representative-agent model predicts positive return comovement for assets with similar cashflows. This motivates the study of a model with segmented markets that are connected through the credit market with heterogeneous agents. When homebuyers in the model are poorer relative to their future dividends, the credit market allows them to use the savings of richer stockholders to buy housing. In this model, bad news about the whole economy can explain negative housing betas. Demographics, institutional entry into housing markets, and foreign investments are candidates for positive betas after the GFC.

Many aspects of the analysis invite further research. Several extensions of the segmented-markets model appear promising. First, the data show that housing cashflow growth is less volatile than stock cashflow growth. Introducing this feature would generate an aggregate risk-sharing motive for credit flows between homebuyers and stockholders. Second, returns on individual houses contain substantial idiosyncratic risk. Incorporating this feature is important for capturing the appropriate risk–return trade-off that households face. Doing so likely requires defaultable debt, which enables stockholders to diversify exposure to household-level risks by holding pools of such debt. Third, regional risks and their implications for stock and housing returns remain underexplored and would be another fruitful extension.

This paper examines theoretical channels through which stock and housing returns may be linked. Quantitative analysis is needed to assess which of these channels are empirically most important. Extending the model to include additional overlapping generations would be useful: with two-period lifetimes, credit flows only from young stockholders to young homebuyers, while data on household portfolios show that bonds are held primarily by older households. Capturing this pattern requires longer lifespans and possibly more household types. Another important extension would be to jointly analyze the time-variation in long bond and housing betas. Both betas matter for the return on levered housing, which is the relevant return for most homebuyers. Finally, this analysis focuses on households as the ultimate owners of all assets in the economy. This approach treats financial intermediaries as a veil. In practice, banks and increasingly nonbanks channel credit between households, but they also face their own balance-sheet exposures and financing constraints, that are interesting to study, and represent a potential source for time-variation in betas.

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Appendix A. Monotonicity of the Excess Demand Function

First, we consider the excess demand function for credit, $f(Q) = r_h(Q) - r_s(Q)$, based on unconstrained credit demand (9). The function is defined on the domain $(-\delta_h w_h, \delta_s w_s)$ and is monotonically decreasing since

$$\frac{\partial r_h(Q)}{\partial Q} = -\frac{d_h}{(\delta_h w_h + Q)^2} - \frac{\sigma^2}{\delta_h w_h} \; < \; 0, \tag{A1}$$

$$\frac{\partial r_s(Q)}{\partial Q} = \frac{d_s}{(\delta_s w_s - Q)^2} + \frac{\sigma^2}{\delta_s w_s} \; > \; 0. \tag{A2}$$

Thus, excess credit demand falls with more credit.

Second, we consider the excess demand function $f(Q)$ based on constrained credit demand (11). This function is also monotonically decreasing, since the derivative of the function (11) is also negative:

$$\frac{\partial r_h(Q)}{\partial Q} = -\frac{\phi \delta_h w_h}{Q^2} < 0. \tag{A3}$$

Appendix B. Proof of Proposition 2

Proof of part i. We use excess credit demand $f(Q)$, based on unconstrained credit demand (9), and solve for the equilibrium $f(Q^*) = 0$. The partial derivatives are

$$\frac{\partial f(Q)}{\partial Q} = \Big(-\frac{d_h}{(\delta_h w_h + Q)^2} - \frac{\sigma^2}{\delta_h w_h} \Big) - \Big(\frac{d_s}{(\delta_s w_s - Q)^2} + \frac{\sigma^2}{\delta_s w_s} \Big) \; < \; 0,$$

and

$$\frac{\partial f(Q)}{\partial \sigma^2} = \frac{\delta_s w_s - Q}{\delta_s w_s} - \frac{\delta_h w_h + Q}{\delta_h w_h} = \alpha_s - \alpha_h. \tag{B1}$$

By the implicit function theorem (IFT),

$$\frac{dQ^*}{d\sigma^2} = -\frac{\frac{\partial f(Q)}{\partial \sigma^2}}{\frac{\partial f(Q)}{\partial Q}} = \frac{\alpha_h - \alpha_s}{\frac{\partial f(Q)}{\partial Q}} < 0,$$

because under Assumption A, we know from Proposition 1 that homeowners borrow from stockowners ($Q > 0$), implying $\alpha_h > \alpha_s$. When credit declines, the price–dividend ratio for stocks $v_s^* = (\delta_s w_s - Q^*)/d_s$ increases, while the price–dividend ratio for housing $v_h^* = (\delta_h w_h + Q^*)/d_h$ decreases. The response of the interest rate is

$$\frac{dr^*}{d\sigma^2} = \frac{\partial r_s(Q)}{\partial \sigma^2} + \frac{\partial r_s(Q)}{\partial Q}\frac{\partial Q^*}{\partial \sigma^2} = -\alpha_s + \frac{\partial r_s(Q)}{\partial Q}\frac{dQ^*}{d\sigma^2} < 0,$$

because the slope of credit supply (A2) is positive and credit falls.

Proof of part ii. We use excess demand $f(Q)$ based on constrained credit demand (11) and solve for the equilibrium $f(Q^*) = 0$. Since constrained credit demand does not depend on expected growth,

$$\frac{\partial f(Q)}{\partial \mu} = -1.$$

Moreover, combining equations (A3) and (A2), we get

$$\frac{\partial f(Q)}{\partial Q} = -\frac{\phi \delta_h w_h}{Q^2} - \Big(\frac{d_s}{(\delta_s w_s - Q)^2} + \frac{\sigma^2}{\delta_s w_s}\Big) < \ 0.$$

By the IFT,

$$\frac{dQ^*}{d\mu} = -\frac{\frac{\partial f(Q)}{\partial \mu}}{\frac{\partial f(Q)}{\partial Q}} = \frac{1}{\frac{\partial f(Q)}{\partial Q}} \ < \ 0.$$

For uncertainty, the partial derivative is

$$\frac{\partial f(Q)}{\partial \sigma^2} = \frac{\delta_s w_s - Q}{\delta_s w_s} = \alpha_s \ > \ 0. \tag{B2}$$

By the IFT,

$$\frac{dQ^*}{d\sigma^2} = -\frac{\frac{\partial f(Q)}{\partial \sigma^2}}{\frac{\partial f(Q)}{\partial Q}} > 0.$$

In response to bad news about the economy, credit increases, the price–dividend ratio for stocks $v_s^* = (\delta_s w_s - Q^*)/d_s$ declines, and the price–dividend ratio for housing $v_h^* = (\delta_h w_h + Q^*)/d_h$ increases. The response of the interest rate to higher uncertainty is

$$\frac{dr^*}{d\sigma^2} = \frac{\partial r_s(Q)}{\partial Q}\frac{dQ^*}{d\sigma^2} + \frac{\partial r_s(Q)}{\partial \sigma^2} = \frac{\frac{\partial r_h(Q)}{\partial Q}}{\frac{\partial r_h(Q)}{\partial Q} - \frac{\partial r_s(Q)}{\partial Q}}\frac{\partial r_s(Q)}{\partial \sigma^2} < 0,$$

because the derivative of credit supply with respect to σ^2 equals $-\alpha_s$ and the fraction with derivatives is positive.

Appendix C. Proof of Proposition 3.iii

Let $S \equiv \delta_s w_s$, $H \equiv \delta_h w_h$, and consider the unconstrained credit market schedules

$$r_d(Q;\lambda) = \frac{d_h}{\lambda H + Q} + \mu - \sigma^2 \frac{\lambda H + Q}{\lambda H}, \qquad r_s(Q;\lambda) = \frac{d_s}{\lambda S - Q} + \mu - \sigma^2 \frac{\lambda S - Q}{\lambda S}$$

defined on $Q \in (-\lambda H, \lambda S)$.

The excess credit demand is $f(Q;\lambda) \equiv r_d(Q;\lambda) - r_s(Q;\lambda)$. The equilibrium (Q^*, r^*) solves $f(Q^*;\lambda) =$

0 and $r^* = r_s(Q^*;\lambda) = r_d(Q^*;\lambda)$. The equilibrium price dividend ratios are $v_s^* = (\lambda S - Q^*)/d_s$ and $v_h^* = (\lambda H + Q^*)/d_h$. We want to show $dv_s^*/d\lambda > 0$ and $dv_h^*/d\lambda > 0$.

The derivatives are

$$\frac{\partial r_d(Q;\lambda)}{\partial Q} = -\frac{d_h}{(\lambda H + Q)^2} - \frac{\sigma^2}{\lambda H} < 0, \qquad \frac{\partial r_s(Q;\lambda)}{\partial Q} = \frac{d_s}{(\lambda S - Q)^2} + \frac{\sigma^2}{\lambda S} > 0,$$

and hence

$$\frac{\partial f(Q;\lambda)}{\partial Q} = \frac{\partial r_d(Q;\lambda)}{\partial Q} - \frac{\partial r_s(Q;\lambda)}{\partial Q} < 0.$$

By the IFT,

$$\frac{dQ^*}{d\lambda} = -\frac{\frac{\partial f(Q;\lambda)}{\partial \lambda}}{\frac{\partial f(Q;\lambda)}{\partial Q}}. \tag{C1}$$

Moreover, we have

$$\frac{\partial f(Q;\lambda)}{\partial \lambda} = \frac{\partial r_d(Q;\lambda)}{\partial \lambda} - \frac{\partial r_s(Q;\lambda)}{\partial \lambda} = \underbrace{\frac{d_s S}{(\lambda S - Q)^2}}_{>0} - \underbrace{\frac{d_h H}{(\lambda H + Q)^2}}_{<0} + \underbrace{\frac{\sigma^2 Q}{\lambda^2}\left(\frac{1}{H} + \frac{1}{S}\right)}_{>0}.$$

We can bound the response of credit to a scaling of incomes

$$-H < \frac{dQ^*}{d\lambda} < S.$$

Proof. Using (C1), the bounds are equivalent to

$$-H\frac{\partial f(Q;\lambda)}{\partial Q} + \frac{\partial f(Q;\lambda)}{\partial \lambda} > 0, \qquad -S\frac{\partial f(Q;\lambda)}{\partial Q} - \frac{\partial f(Q;\lambda)}{\partial \lambda} > 0.$$

Some algebra gives, for all $Q \in (-\lambda H, \lambda S)$,

$$-S\frac{\partial f(Q;\lambda)}{\partial Q} - \frac{\partial f(Q;\lambda)}{\partial \lambda} = \frac{d_h(S+H)}{(\lambda H + Q)^2} + \sigma^2 \frac{S+H}{\lambda H}\underbrace{\left(1 - \frac{Q}{\lambda S}\right)}_{>0} > 0,$$

$$-H\frac{\partial f(Q;\lambda)}{\partial Q} + \frac{\partial f(Q;\lambda)}{\partial \lambda} = \frac{d_s(S+H)}{(\lambda S - Q)^2} + \sigma^2 \frac{S+H}{\lambda S}\left(1 + \frac{Q}{\lambda H}\right) > 0.$$

Finally, we use these bounds to sign the response of the price–dividend ratios:

$$\frac{dv_s}{d\lambda} = \frac{1}{d_s}\left(S - \frac{dQ^*}{d\lambda}\right) > 0, \qquad \frac{dv_h}{d\lambda} = \frac{1}{d_h}\left(H + \frac{dQ^*}{d\lambda}\right) > 0.$$

Appendix D. Statement in Footnote 5

Let the unconstrained credit market schedules be

$$r_d(Q;W_h) = \frac{d_h}{W_h+Q} + \mu - \sigma^2\frac{W_h+Q}{W_h}, \qquad r_s(Q) = \frac{d_s}{\delta_s w_s - Q} + \mu - \sigma^2\frac{\delta_s w_s - Q}{\delta_s w_s}.$$

The excess credit demand function is $f(Q;W_h) = r_d(Q;W_h) - r_s(Q)$. The unconstrained equilibrium (Q^*, r^*) solves $f(Q^*;W_h) = 0$ and $r^* = r_s(Q^*) = r_d(Q^*;W_h)$. The price–dividend ratios are

$$v_s^* = \frac{\delta_s w_s - Q^*}{d_s}, \qquad v_h^* = \frac{W_h + Q^*}{d_h}.$$

On the domain $Q \in (-W_h, \delta_s w_s)$,

$$\frac{\partial f(Q;W_h)}{\partial Q} = \Big(-\frac{d_h}{(W_h+Q)^2} - \frac{\sigma^2}{W_h}\Big) - \Big(\frac{d_s}{(\delta_s w_s - Q)^2} + \frac{\sigma^2}{\delta_s w_s}\Big) < 0,$$

$$\frac{\partial f(Q;W_h)}{\partial W_h} = \frac{\partial r_d(Q;W_h)}{\partial W_h} = -\frac{d_h}{(W_h+Q)^2} + \frac{\sigma^2\, Q}{W_h^2} \quad \text{sign ambiguous.}$$

By the IFT,

$$\frac{dQ^*}{dW_h} = -\frac{\frac{\partial f(Q;W_h)}{\partial W_h}}{\frac{\partial f(Q;W_h)}{\partial Q}} = \frac{\frac{\partial f(Q;W_h)}{\partial W_h}}{\left|\frac{\partial f(Q;W_h)}{\partial Q}\right|}, \qquad \frac{dr^*}{dW_h} = \frac{\partial r_s(Q;W_h)}{\partial Q}\,\frac{dQ^*}{dW_h},$$

implying that dr^*/dW_h has the same sign as $\partial f/\partial W_h$. For the price–dividend ratios,

$$\frac{dv_s}{dW_h} = -\frac{1}{d_s}\frac{dQ^*}{dW_h}, \qquad \frac{dv_h}{dW_h} = \frac{1}{d_h}\Big(1 + \frac{dQ^*}{dW_h}\Big) = \frac{1}{d_h}\Big(\frac{\left|\frac{\partial f(Q;W_h)}{\partial Q}\right| + \frac{\partial f(Q;W_h)}{\partial W_h}}{\left|\frac{\partial f(Q;W_h)}{\partial Q}\right|}\Big).$$

Moreover,

$$\left|\frac{\partial f(Q;W_h)}{\partial Q}\right| + \frac{\partial f(Q;W_h)}{\partial W_h} = \underbrace{\Big(\frac{d_s}{(\delta_s w_s - Q)^2} + \frac{\sigma^2}{\delta_s w_s}\Big)}_{>0} + \underbrace{\frac{\sigma^2}{W_h}}_{>0} + \underbrace{\frac{\sigma^2 Q}{W_h^2}}_{\geq 0} \; > \; 0,$$

so

$$\frac{dv_h^*}{dW_h} > 0.$$

The sign of credit's response is governed by the threshold

$$\frac{dQ^*}{dW_h} \gtrless 0 \iff \sigma^2\, Q^*(W_h + Q^*)^2 \gtrless d_h\, W_h^2\,.$$

Thus, in the unconstrained case, the effects on v_s^*, Q^*, and r^* are generally sign-ambiguous, governed by the threshold above. Credit and the interest rate always move in the opposite direction of the price–dividend ratio v_s. For plausible calibrations, the variance of aggregate growth σ^2 is small relative to the share of housing services in GDP, in which case the lower inequality applies. In this case, credit and the interest rate fall.

The constrained credit demand function is

$$r_d(Q;W_h) = \phi\,\frac{W_h+Q}{Q} - 1,$$

while credit supply is unchanged, and $f(Q;W_h) = r_d(Q;W_h) - r_s(Q;W_h)$ has derivatives

$$\frac{\partial r_d(Q;W_h)}{\partial W_h} = \frac{\phi}{Q} > 0, \quad \frac{\partial r_d(Q;W_h)}{\partial Q} = -\frac{\phi W_h}{Q^2} < 0.$$

We thus have $\partial f(Q;W_h)/\partial Q < 0$ and

$$\frac{dQ^*}{dW_h} = -\frac{\frac{\partial f(Q;W_h)}{\partial W_h}}{\frac{\partial f(Q;W_h)}{\partial Q}} = -\frac{\frac{\partial r_d(Q;W_h)}{\partial W_h}}{\frac{\partial r_d(Q;W_h)}{\partial Q} - \frac{\partial r_s(Q;W_h)}{\partial Q}} > 0\,, \qquad \frac{dr^*}{dW_h} = \frac{\partial r_s(Q)}{\partial Q}\,\frac{dQ^*}{dW_h} > 0\,.$$

Consequently,

$$\frac{dv_s^*}{dW_h} = -\frac{1}{d_s}\frac{dQ^*}{dW_h} < 0\,, \qquad \frac{dv_h^*}{dW_h} = \frac{1}{d_h}\left(1 + \frac{dQ^*}{dW_h}\right) > \frac{1}{d_h} > 0\,.$$