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ARTICLE

House prices and rents: a reappraisal†

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Abstract

In this work, we introduce rental markets in a general equilibrium model with borrowing constraints and infinitely lived agents. We estimate our model using standard Bayesian methods and match US data on recent decades. We highlight a crucial relationship that strongly links interest rates, house prices, and rents. It represents agents' arbitrage when choosing their degree of participation in the housing market (i.e. their real estate holdings). This framework is particularly well suited for explaining how policy-induced changes in households' preferences have driven house prices up while pushing rent-price ratios down in the aftermath of the Covid-19 outbreak. It also allows us to parsimoniously track the unequal impact of these changes on agents' decisions and welfare, which crucially depends on whether they are owners or renters.

Keywords: Housing; rental markets; collateral constraints; financial frictions

1. Introduction

In the midst of the US economy's struggle to survive the Covid-19 crisis, its housing market has experienced a boom. At the same time, rents have generally decreased, with some exceptions [see Gupta et al. (2022)], and have stagnated on average. While the (small) fall in rents is in line with past evidence on pandemics, the joint increase in house prices contradicts it.[1] In contrast, housing markets in G7 countries during the years of the financial crisis featured a dramatic drop in prices, an increase in rent-price ratios, and a slight decrease in rents. Recent trends over the last decades have thus featured high volatility and seem to be consistent with a disconnect between house prices and rents (see Sommer et al. (2013), among others) or between asset returns and housing returns [see e.g. Favilukis et al. (2017)]. More generally, housing dynamics over the last decades call into question our ability to understand the mechanisms behind the joint dynamics of rents and house prices, and the underlying arbitrages agents are facing in the housing market.

The macroeconomic relevance of such large fluctuations arises from the fact that housing is a special good, because it provides housing services and, at the same time, is the most common

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asset in households' portfolios. Therefore, developments in housing markets can have significant effects on households' welfare. However, the latter are unequal and depend on exposure to the housing market, which differs markedly based on whether one is a renter or a homeowner [see e.g. Christophers (2021)]. Because of its specificity, housing services can be accessed in two ways: either by paying rent or purchasing real estate at the housing price. This leads to an arbitrage between rents and house prices, which must also incorporate the opportunity cost associated with other investment opportunities. In addition, when investing in the real estate market, households cannot neglect potential borrowing costs.

For the purpose of examining the tradeoffs that underlie recent housing market dynamics, we need to go beyond the standard focus on owners-inhabitants alone and account for both tenants and landlords in addition to borrowers and lenders. In this paper, we build a model that accounts for rental, real estate, and credit markets.[2] We explicitly incorporate *endogenous*[3] rental markets, and the resulting population in our model is composed of *landlords*, who rent housing to tenants and lend funds to debt-constrained *owner-inhabitants*.

Starting from Iacoviello (2005), a rich literature has remarked the importance of housing loans to explain housing and business cycle fluctuations (see, for instance, Guerrieri and Iacoviello (2017); Ferrero (2015); Iacoviello and Neri (2010); Justiniano et al. (2019), among many others). The benchmark structure of these models allows us to account for the fact that a significant share of the population has debt linked to real estate. Households' arbitrages must therefore account for the fact that housing also acts as collateral and that its price fluctuations have implications for credit access. This approach, which focuses on the "intensive margin" of households' decisions, has the advantage that all equilibrium prices and quantities are endogenously determined. It also shows that the introduction of collateral constraints allows to generate amplification mechanisms and correlations, which help explain some key empirical facts. However, this branch of the macroeconomic literature does not generally account for rental markets, even though about one-third of the US population rents (see also Andrews and Caldera Sánchez (2011) for more evidence).[4]

Since real estate represents most households' main wealth holdings, several contributions have focused on life-cycle portfolio facts (see Davis and Van Nieuwerburgh (2015) for a review). In this literature, assumptions on house prices vary[5] but earnings are in general exogenous. Sommer et al. (2013) contribute by incorporating households' decisions regarding rental property in a model that examines housing prices and rents.[6] The model's equilibrium is the result of the interaction of heterogeneous agents à la Aiyagari-Bewley-Huggett in a stochastic environment with incomplete markets. Sommer et al. (2013)'s model focuses on the "extensive margin" of housing markets; interest rates and incomes are assumed to be exogenous. Also, Favilukis et al. (2017) use a general equilibrium business cycle model to study the impact of risk on rent-price dynamics and wealth distribution in response to credit shocks. However, they do not introduce the rental market. Conversely, closer to our framework, Kiyotaki et al. (2011) study the implications of an unexpected increase in the land's share of housing for the life-cycle wealth distribution and the relationship between housing prices and rents. More recently, Kaplan et al. (2020) explicitly account for rental markets in studying the role of beliefs in the housing bust during the Great Recession. Analogously, Greenwald and Guren (2021) study the impact of credit conditions on rent-to-price ratios and ownership rates during the 2000s. Recently, Dong et al. (2022) study the response of house and rent prices to credit shocks.[7]

In this paper, we study housing market fluctuations in a model à la Iacoviello (2005) by incorporating both collateral constraints and rental markets. Our first contribution is theoretical, in that we provide foundations for introducing rental markets to standard DSGE models with infinitely lived agents and borrowing constraints. We show how it is possible to introduce a partition in the population where heterogeneous discounting entails fractional homeownership.[8] The population eventually consists of three types of agents: (i) a landlord willing to rent housing and lend funds to other agents, (ii) a homeowner who is subject to a collateral constraint that limits his access to credit to buy housing, and (iii) renters. We show that allowing for *imperfect* rental markets (in the sense that rented units are imperfect substitutes for owned ones) introduces a tradeoff, which is crucial for endogenous rental markets that interact with binding collateral constraints,[9] whereas the most patient agent solves a standard dynamic program and is thus willing to save, all less patient agents do not [see Becker and Foias (1987)]. For the purpose of purchasing housing services, less patient agents can buy real estate. This comes at the cost of paying the interest rate and down payment. Moreover, because the loan-to-value ratio is smaller than one, they end up being net savers. Alternatively, they can choose to rent housing services and have zero net savings at the cost of facing the imperfections in the rental market. Because rented units entail fewer housing services, this implies utility losses. We show how agents decide whether to be collateral-constrained owner-inhabitants or renters, based on their degree of impatience (i.e. their opportunity cost of saving). This framework allows us to pin down the arbitrage that households face when deciding on housing holdings. The resulting asset-pricing equation is specific to housing and links house prices, the rent-price ratio, and interest rates [in the spirit of Favilukis et al. (2017)].

We then confront our model with the data. We first estimate the model using Bayesian techniques and generalize the framework of Iacoviello and Neri (2010) to account for rental markets. This allows us to calibrate our model realistically and then simulate it using standard perturbation methods.[10] We believe that our framework is particularly useful for understanding the joint dynamics of prices and aggregates in the housing market. We thus study the behavior of the model under standard macroeconomic shocks and provide explanations for the main mechanisms. Our estimated model does a good job of matching standard moments of the macroeconomic aggregates as well as the main variables of housing markets during the last decades. This highlights the crucial role of the arbitrage equation that links house prices, rents, and interest rates in driving housing markets. It thus contradicts the idea of a fundamental disconnect between house prices and rents [Sommer et al. (2013)].

We finally provide an application of our model and argue that it possesses all salient features necessary to explain and track housing trends following the outbreak of Covid-19. As highlighted by several scholars, that puzzling boom has been indeed a “remarkable record” (Robert Shiller, 3 July 2020 on the New York Times) contrasting with the above-cited empirical evidence on previous pandemics.[11] Restrictions in response to the pandemic have imposed strong limits on current non-durable consumption but less on durable consumption and durable investment. Moreover, other factors like fear have contributed to trigger the massive change in consumers’ behaviors during that period, reducing consumers’ traffic to US stores by 60% [see Goolsbee and Syverson (2021)]. We show that this shock to *intertemporal* preferences entails both a decrease in interest rates *and* an increase in savings, consistent with the evidence. We show how the shock propagates throughout the housing market to reproduce recent trends in housing. In response to the intertemporal tilt in consumption, interest rates decrease. Because of the collateral constraint, the fall in credit costs triggers strong increase in house prices, because it enables access to more real estate. However, because of the strong and positive relationship between interest rates, house prices, and rents, lower interest rates, together with higher house prices, must be compensated for by a decrease in rents. The relationship between interest rates and rents featured in our model is thus critical for matching recent trends and is consistent with the empirical evidence of Dias and Duarte (2019). It also highlights how low-interest rates push down rents. Finally, we show how standard *intratemporal* shocks to housing preferences [as in Guerrieri and Iacoviello (2017)] lead to joint dynamics of house prices and rent-price ratios that are not consistent with what occurred during the Great Recession and the Covid-19 pandemic.

Our framework also allows us to track the (unequal) effect of shocks on heterogeneous agents. We show that these dynamics tend to redistribute welfare from landlords toward indebted homeowners. This is because the credit costs of the latter decrease, whereas landlords’ revenues are dampened by low-interest rates and falling rental returns.

The paper is organized as follows. Section 2 introduces a simplified version of the model and provides a proof for agents' partition, together with the main intuitions. Section 3 presents the full model. The estimation and the ability of the model to match data are discussed in Section 4. Section 5 analyzes the dynamic properties of the model, and Section 6 considers current trends in housing markets. Section 7 concludes.

2. A tractable model with housing rental

In this section, we show how it is possible to obtain a partition of the population where renters and indebted homeowners coexist and collateral constraints are binding in a standard framework à la Iacoviello (2005) (in which rental markets have been assumed away).[12] To provide an intuitive explanation of the main mechanism, we first introduce a simple endowment economy in a partial equilibrium setting. We later enrich this framework so as to account for empirically relevant features in a general equilibrium framework.

We consider a population with N agents, indexed by $i = 1, \ldots, N$. Each agent is an expected utility maximizer over an infinite lifespan and faces at date t a problem that can be written as follows:

$$\max_{\{c_{it},x_{it},h_{it},z_{it},d_{it}\}} u_i\big(c_{it}, hs_{it}\big) + \mathbb{E}_t \textstyle\sum_{j=1}^{\infty} \prod_{\varphi=1}^{j} \beta_{it+\varphi} u_i\left(c_{it+j}, hs_{it+j}\right)$$

$$\text{s.t.} \left| \begin{array}{l} hs_{it} = h_{it}x_{it-1} + \phi z_{it}, \\ y_{it} + d_{it} + p_t(1-\delta_x)\, x_{it-1} + p_t l_t \left(1 - h_{it}\right) x_{it-1} \\ = c_{it} + R_{t-1}d_{it-1} + p_t x_{it} + p_t l_t z_{it}, \\ d_{it} \leq m\,(1-\delta_x)\, x_{it}\mathbb{E}_t p_{t+1}, \\ x_{it} \geq 0, z_{it} \geq 0, c_{it} \geq 0, 0 \leq h_{it} \leq 1, \\ x_{it-1} \text{ given}, d_{it-1} \text{ given}. \end{array} \right. \tag{1}$$

The utility u_i of agent i is a function of the consumption of non-durable goods, c_{it}, and housing services, hs_{it}.[13] We assume that the utility is increasing and concave in both arguments and that marginal utilities tend to infinity when an argument equals zero. The time discount of each agent is stochastic and denoted by β_{it}. In this general framework, we do not take a stand on the precise stochastic process defining β_{it}. We just assume that for all t, it satisfies : $1 > \beta_{1t} > \beta_{2t} > .. > \beta_{Nt} > 0$. The agent characterized by β_{1t} is also called the "dominant consumer," as his discount factor determines the equilibrium interest rate [see Becker and Foias (1987)].

The first constraint shows that housing services can be consumed in two ways. Either agent i has inherited some housing, x_{it-1}, from period $t-1$, in which case he or she can decide to own-occupy a share $h_{it} \in [0, 1]$ of it and rent a share $1 - h_{it}$ to other agents. This agent can also decide to rent housing services ϕz_{it} from other agents with $\phi \in (0, 1)$.[14] As $\phi < 1$, an agent who decides to rent z_{it} units of housing to another agent would only transfer $\phi z_{it} < z_{it}$ units of *housing services* to this agent.[15] We thus interpret $\phi < 1$ as implying that the rental market is imperfect in the sense that rented units are imperfect substitutes to owned ones. We do not model the source of this imperfection which could stem from tenants' limited discretion over the way the house is used or modified, preferential tax treatments for housing, or rental premiums resulting from moral hazard [see e.g. Henderson and Ioannides (1983)].[16]

The second constraint in problem (1) is the budget constraint faced by agent i. The latter receives an exogenous income $y_{it} > 0$, can borrow d_{it} from other agents, resells the depreciated housing he or she owns $(1-\delta_x)\, x_{it-1}$ at price p_t, where the latter is the price for housing (the relative price of housing in terms of the consumption good, which is the numeraire), and receives income $p_t l_t \left(1 - h_{it}\right) x_{it-1}$ from housing rented to other agents, where $p_t l_t$ is the rent paid by renters, and l_t is the rent-to-price or rent-price ratio.[17] Those funds can be used to purchase consumption goods c_{it}, repay debt $R_{t-1}d_{it-1}$ (where R_{t-1} is the gross real interest rate set in $t-1$), purchase new housing x_{it} at price p_t and pay for the z_{it} rented units of housing.

The third constraint is a standard collateral constraint. It states that the debt d_{it} of agent i cannot be larger than a share $m \in (0, 1)$ of the expected value of the net-of-depreciation housing stock $(1-\delta_x)\, x_{it}$ she owns, with $\delta_x \in [0, 1)$. The collateral constraint can be justified by enforcement problems [see Kiyotaki and Moore (1997)]. We finally mention that owned housing, rented housing, and consumption cannot be negative.

Propositions 1 and 2 characterize the endogenous partition of the population of our model.

Proposition 1. *In the economy, an agent is either: a tenant, formally defined such that* $x_{it}=0$ *and* $z_{it+1}>0$*, an owner-occupier, defined such that* $x_{it}>0$ *and* $h_{it+1}=1$*, or a landlord, defined such that* $x_{it}>0$*,* $h_{it+1}\in(0,1)$ *and* $z_{it+1}=0$.

Proof. See Online Appendix A. □

Proposition 1 establishes the optimal behavior of an agent described by problem (1). It eliminates aberrant behaviors and shows that only three types of agents are possible: (i) tenants, who do not own the housing they live in, (ii) owner-occupiers, who occupy all the housing they own, and (iii) landlords, who occupy a share of the housing they own and rent the rest. All other possibilities are ruled out as they are suboptimal. For an agent, belonging to a given type will depend on the values of the equilibrium variables and preference parameters and functions. As in Becker and Foias (1987), we now characterize the partition of the population between the different types of agents by focusing on the steady state.[18]

Proposition 2. *At the deterministic steady state, the dominant consumer is the only landlord. This agent lends funds to owner-inhabitants till their borrowing limit and rents some housing to tenants. There exists a unique* $\bar{\beta}_i \in (0, \beta_1)$ *such that all agents with a* $\beta_i < \bar{\beta}_i$ *are tenants and all agents with a* $\beta_i < \left[\bar{\beta}_i, \beta_1\right)$ *are owner-occupiers.*

Proof. See Online Appendix A. □

Proposition 2 shows how the partition of the population around the steady state depends on discount rate values. In particular, only the most patient agent is a landlord. There is also a set of less patient agents who are owner-occupiers, while the least patient ones are tenants. This result generalizes the setting of Becker and Foias (1987) to an economy with housing and rental.

To understand the intuition behind this result notice that if there were no rental markets, the dominant consumer would lend funds to all less patient ones, who would in turn use them to purchase real estate. As the collateral constraint is linked to a down payment, all impatient consumers would still be net savers because the value of their homes would exceed the value of their debt. Introducing a rental market offers another way for less patient consumers to buy housing services. One possibility is still to borrow and purchase the houses they occupy. However, this comes at the cost of having positive net savings.[19] The other possibility is to rent housing and have zero net savings. However, because of rental market imperfections (associated with ϕ being lower than one), renting housing services is also costly and entails a utility loss. There is thus a tradeoff. The above proposition implies that relatively patient consumers favor the first option because they have a lower opportunity cost of having positive net savings. In contrast, because of a greater opportunity cost of saving, very impatient consumers prefer renting.

Proposition 2 shows that an endogenous partition of landlords, owner-inhabitants, and tenants can be obtained in a model with agents having infinite lifespans, because of discount factor heterogeneity. This framework allows us to track the different behavior of agents, that crucially depends on their housing status, and the implications for welfare.[20] As in Becker and Foias (1987), the mechanisms driving this result are very strong and allow us to extend our model so as to account for realistic features such as endogenous labor and capital accumulation. The full model that we present in what follows will be featured by analogous closed-form solutions. Of course, even if this model is more "realistic," it remains a very simplified form of reality. In particular, the partitioning of the population in the housing market is based only on differences in discount rates, whereas it is clear that many other factors can contribute to this stratfication.[21]

2.1. Returns

We now focus our attention on returns because they represent the link between finance and the housing market. In general equilibrium, housing returns and bond returns need indeed to be equalized. Proposition 3 shows how interest rates are structurally linked to house prices and rent-price ratios.

Proposition 3. *In the neighborhood of the deterministic steady state, housing prices, rents, and interest rates are linked by the following relationship:*

$$R_t = \mathbb{E}_t \frac{p_{t+1}}{p_t} \left[(1-\delta_x) + l_{t+1} \right] \varepsilon_{t+1}, \tag{2}$$

where

$$\varepsilon_{t+1} := \frac{\beta_{1t+1} u'_{c_{1t+1}}}{\mathbb{E}_t \beta_{1t+1} u'_{c_{1t+1}}}. \tag{3}$$

Proof. See Online Appendix A. □

Without uncertainty, $\varepsilon_{t+1} = 1$, and equation (2) is a standard arbitrage equation. It equates the gross interest rate on bonds to the return of a unit of non-depreciated housing.[22] With stochastic shocks, the gap between the expected and the realized discounted utility of the most patient agent (i.e. the dominant consumer) influences the relationship. Indeed, risk and volatility can affect the nature of the relationship between interest rates, house prices, and the rent-price ratios.

Equation (2) has similar counterparts in the literature and, notably, is reminiscent of the definition of *housing returns* in Favilukis et al. (2017), once accounting for the *housing premium* between bond rates and housing returns. However, as Favilukis et al. (2017) do not explicitly model rental markets, they replace the term l_{t+1} by a marginal utility ratio—which is the result of a weighted average of the population's marginal utilities and accounts for a weighted average of discount factors. The wealth distribution of the population is key in their article as it determines risk sharing and risk premia. In contrast, in our work, both l_{t+1} and ε_{t+1} are functions of the marginal utilities of the dominant consumer only. The latter also pins down both interest rates and rents. This is consistent with the main mechanism in Kaplan et al. (2020), where non-constrained homeowners play a key role in housing market dynamics. Notice in particular that the arbitrage equation *itself* is pinned down by the dominant consumer. Indeed, the landlord is the only agent who is an active player on the (i) credit market, (ii) the real estate market and the (iii) rental market.[23] Therefore, the equilibrium is imposed by the portfolio arbitrage of landlords.

3. The full model

The results of the previous section have shown that it is possible to introduce an explicit rental market in a framework with infinitely lived agents. In particular, it showed that an endogenous partition of the population into landlords, owner-occupiers, and renters arises based on discount factor heterogeneity. We now use these insights to study the dynamics of housing and rental markets in a standard business cycle model.

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To do so, we enrich the above endowment economy in order to account for several empirically realistic features. In later sections, we assess the ability of our full model to match various aggregate moments. Our model features two productions sectors $s = \{c, h\}$ where c refers to consumption goods and h to housing goods, respectively. The economy is inhabited by the three types of representative agents following Proposition 1: landlords, owner-inhabitants, and tenants. The economy is hit by a set of stochastic shocks which are standard in the macroeconomic literature on housing.

3.1. Households

The three different types of agents are indexed by $i = 1, 2, 3$ and have different time preference parameters, where β_i satisfies $1 > \beta_1 > \beta_2 > \beta_3 > 0$. Agent 1 (characterized by β_1) is the most patient ones and is thus *landlords*. Consistently with our results in Section 2, the discount factors of agents 2 and 3 are chosen such that they are *owner-occupiers* and *renters*, respectively (see Online Appendix A for a characterization of thresholds). As in Guerrieri and Iacoviello (2017), $\tilde{\beta}_t$ is a random variable that captures shocks to *intertemporal* preferences and satisfies:[24]

$$\log \tilde{\beta}_t = \rho_\beta \log \tilde{\beta}_{t-1} + \epsilon_{\beta t}. \tag{4}$$

In each period, agent i discounts date t with $\beta_i^t \tilde{\beta}_t$. Notice also that the way we incorporate $\tilde{\beta}_t$ into agents' preferences ensures that the status of agents does not change in response to the shock. We allow the population of each type to be of different size, so as to match empirical evidence. The size of the population of agent 1 is used as a normalizer and is set to 1. We then denote by $\omega_2 > 0$ and $\omega_3 \Omega_t > 0$ the relative shares of agents of type 2 and 3 with respect to the one of type 1. To account for changes in the homeownership rate, we introduce Ω_t, which is a random variable that captures shocks to the proportion of renters in the population.[25] It satisfies:

$$\log \Omega_t = \rho_\Omega \log \Omega_{t-1} - \epsilon_{\Omega t}. \tag{5}$$

and is consistent with the stationarity of the model. The homeownership rate at time t is thus defined according to agents' population shares as $(1 + \omega_2)/(1 + \omega_2 + \omega_3 \Omega_t)$, and the share of landlords among homeowners is $1/\,(1 + \omega_2)$.

Let us first consider the individual problem for agent 1, who are the landlords and the only ones willing to save in equilibrium (see Propositions 1 and 2). They are thus the sole owners of both the capital stocks and land. Following Iacoviello (2005), the expected utility of an agent of type 1 is:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta_1^t \tilde{\beta}_t \left[\ln c_{1t} + j_t \ln \left(h_t x_{1t-1} \right) - \chi_1 \frac{n_{1t}^\eta}{\eta} \right], \tag{6}$$

where c_{1t} is the consumption of non-durables, $h_t x_{1t-1}$ is the consumption of housing services, and n_{1t} is hours worked. An agent of type 1 owns x_{1t-1} units of housing but rents a share $(1 - h_t)$ of this housing stock to other agents, thus effectively consuming $h_t x_{1t-1}$ units of housing services. The parameter $\eta > 1$ determines the elasticity of labor supply, while the parameter $\chi_1 > 0$ captures the preference for leisure. As in Iacoviello (2005), we allow for *intratemporal* shocks to housing preference, j_t with:

$$\log j_t = \rho_j \log j_{t-1} + (1 - \rho_j) \log j_{ss} + \epsilon_{jt}, \tag{7}$$

where $j_{ss} > 0$ is the steady-state value of j_t and where ϵ_{jt} is a shock correlated to $\epsilon_{\Omega t}$. The increase in the demand for housing is thus correlated to the increase of the share of homeowners.

The budget constraint of agents of type 1 is as follows:

$$\begin{aligned} p_t \left[(1 - \delta_x) + l_t \left(1 - h_t \right) \right] x_{1t-1} + r_t^c k_{t-1}^c + r_t^h k_{t-1}^h + p_t^q \left(1 + l_t^q \right) q_{t-1} \\ + d_{1t} + w_t n_{1t} = c_{1t} + R_{t-1}^d d_{1t-1} + i_t^c + i_t^h + p_t x_{1t} + p_t^q q_t \end{aligned} \tag{8}$$

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The left-hand side of the equation corresponds to the resources of an agent of type 1. They are the sum of the value of the previous-period housing stock, $p_t(1-\delta_x)x_{1t-1}$, where p_t is the housing price and $\delta_x \in [0,1]$ the depreciation rate of housing; the rent received on the $(1-h_t)$ share of rented units, where l_t is the rent-price ratio; the returns on investments in the two sectors, $r_t^s k_{t-1}^s$, where r_t^s is the rental price of capital of sector s and k_{t-1}^s is the capital invested in sector s; the value of the land owned by agent 1, $p_t^q q_{t-1}$, where p_t^q is the price and q_{t-1} the quantity; the rent received from the land, $p_t^q(1+l_t^q)q_{t-1}$, where l_t^q is the rent-price ratio for the land; new debt/credit, d_{1t} (as discussed above, agent 1 is always a lender in equilibrium, which implies $d_{1t}<0$); labor income, $w_t n_{1t}$, where w_t is the wage. The right-hand side of (8) represents expenditures. They include consumption of non-durables, the payment of the debt interests at rate R_{t-1}^d, capital investment in both sectors, i_t^s, the purchases of housing and land.[26]

As commonly assumed, land does not depreciate and its quantity is constant and normalized to 1. It effectively acts as an adjustment cost which can increase the volatility of house prices [see, for instance, Iacoviello and Neri (2010)]. Capital in each sector depreciates at rate $\delta_s \in [0,1]$. Investments in those sectors are affected by efficiency shocks as in Christiano et al. (2014), which are denoted Υ_t^s and satisfy:

$$\log \Upsilon_t^s = \rho_{\Upsilon^s} \log \Upsilon_{t-1}^s + \epsilon_{\Upsilon^s t}. \tag{9}$$

Moreover, we introduce adjustment costs [as e.g. in Justiniano et al. (2011), Christiano et al. (2011) or Guerrieri and Iacoviello (2017)], so that capital accumulation in sector s follows:

$$k_t^s = \Upsilon_t^s i_t^s \left[1 - \frac{\phi_s}{2}\left(\frac{i_t^s}{i_{t-1}^s} - 1\right)^2\right] + (1-\delta_s)\, k_{t-1}^s, \tag{10}$$

where $\phi_s \geq 0$ gives the intensity of the inefficiency. As a result of these adjustment costs, the relative price of capital fluctuates.

The problem of agent 1 is to maximize (6) subject to (8) and (10) given $\left(x_{1t-1}, k_{t-1}^c, k_{t-1}^h, q_{t-1}, d_{1t-1}\right)$. The full list of first-order conditions can be found in Online Appendix B.1.

Let us now consider the individual problem of agents 2. Following the previous theoretical results, β_2 is such that, in equilibrium, these agents are owner-inhabitants who borrow up to the limit set by the collateral constraint, and who do not hold any assets except housing (which serves as a collateral for loans). For simplicity, variables referring to agents 2 and 3 are defined as those for agent 1 but are indexed by 2 and 3 respectively. The expected utility of an agent of type 2 is:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta_2^t \tilde{\beta}_t \left[\ln c_{2t} + j_t \ln x_{2t-1} - \chi_2 \frac{n_{2t}^{\eta}}{\eta}\right], \tag{11}$$

with the budget constraint given by:

$$p_t(1-\delta_x)\, x_{2t-1} + d_{2t} + w_t n_{2t} = c_{2t} + R_{t-1}^d d_{2t-1} + p_t x_{2t} \tag{12}$$

As in (1), the collateral constraint writes:

$$d_{2t} \leq m(1-\delta_x)\, x_{2t} \mathbb{E}_t p_{t+1}, \tag{13}$$

where $m>0$ is given.[27] Following Proposition 2, the constraint in (13) is binding. The problem of agent 2 consists in maximizing (11) subject to (12) and (13) for $\left(x_{2t-1}, d_{2t-1}\right)$ given. The full list of first-order conditions can be found in Online Appendix B.2.

Let us finally consider agent 3. Following our theoretical results, we assume that β_3 is such that these agents are renters in equilibrium and therefore hold no assets. The expected utility of an agent of type 3 writes:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta_3^t \tilde{\beta}_t \left[\ln c_{3t} + j \ln (\phi z_{3t}) - \chi_3 \frac{n_{3t}^{\eta}}{\eta} \right], \tag{14}$$

where z_{3t} is the amount of housing rented by this agent and ϕ is kept for consistency with problem (1). We also assume that preference shocks for housing only affect homeowners, so that for agent 3, $j = j_{ss}$. ϵ_{jt} is thus a preference shock for owned housing units as commonly done in the literature.

The budget constraint applying to agent 3 is:

$$w_t n_{3t} = c_{3t} + p_t l_t z_{3t}. \tag{15}$$

Note that, since agent 3 holds no assets, their problem is static and thus does not depend on β_3. The latter only determines the fact that they are renters in equilibrium (see Proposition 2). First-order conditions are presented in Online Appendix B.3.

3.2. Firms

Firms produce in a perfectly competitive environment. As mentioned above, there are two sectors that produce non-durable goods and housing, respectively. The production function of the firms of the consumption sector is given by: $Y_{ct} = A_{ct} K_{ct}^{\gamma_c} L_{ct}^{\alpha_c}$ (with $\gamma_c + \alpha_c = 1$), where K_{ct} and L_{ct} are respectively the capital and labor used by the firms and A_{ct} is an exogenous productivity factor specific to the consumption sector which satisfies:

$$\log A_{ct} = \rho_{A_c} \log A_{ct-1} + \epsilon_{Act}. \tag{16}$$

The production function of the firms of the housing sector is given by: $Y_{ht} = A_{ht} K_{ht}^{\gamma_h} L_{ht}^{\alpha_h} Q_t^{1-\alpha_h-\gamma_h}$ where K_{ht}, L_{ht}, and Q_t are respectively capital, labor, and land used by the firm [see e.g. Iacoviello and Neri (2010)] and A_{ht} is a productivity factor which satisfies:

$$\log A_{ht} = \rho_{A_h} \log A_{ht-1} + \epsilon_{Aht}. \tag{17}$$

where we allow ϵ_{Aht} to be correlated with ϵ_{Act}. First-order conditions of the firms' problem are derived in Online Appendix B.4.

3.3. Equilibrium

There are 8 markets in the economy, which clear in equilibrium. Let us start with the asset markets. Equilibrium in the capital markets of both sectors implies: $K_{ct} = k_{t-1}^c$ and $K_{ht} = k_{t-1}^h$. The equilibrium in the market for land is $Q_t = q_{t-1} = 1$, and the one for debt is $d_{1t} + \omega_2 d_{2t} = 0$. Moreover, the rental market for housing satisfies: $\omega_3 \Omega_t z_{3t} = \left(1 - h_t\right) x_{1t-1}$.

As we assume that labor is perfectly mobile across sectors, the equilibrium condition for the labor market is:

$$L_{ht} + L_{ct} = n_{1t} + \omega_2 n_{2t} + \omega_3 \Omega_t n_{3t}. \tag{18}$$

We now turn to the equilibrium for the two goods markets. The equilibrium condition for non-durable goods is:

$$Y_{ct} = c_{1t} + \omega_2 c_{2t} + \omega_3 \Omega_t c_{3t} + i_t^c + i_t^h, \tag{19}$$

while the equilibrium for the housing good is:

$$Y_{ht} = x_{1t} + \omega_2 x_{2t} - (1 - \delta_x) \left[x_{1t-1} + \omega_2 x_{2t-1} \right]. \tag{20}$$

In the next section, we discuss our procedure to calibrate and estimate the model.

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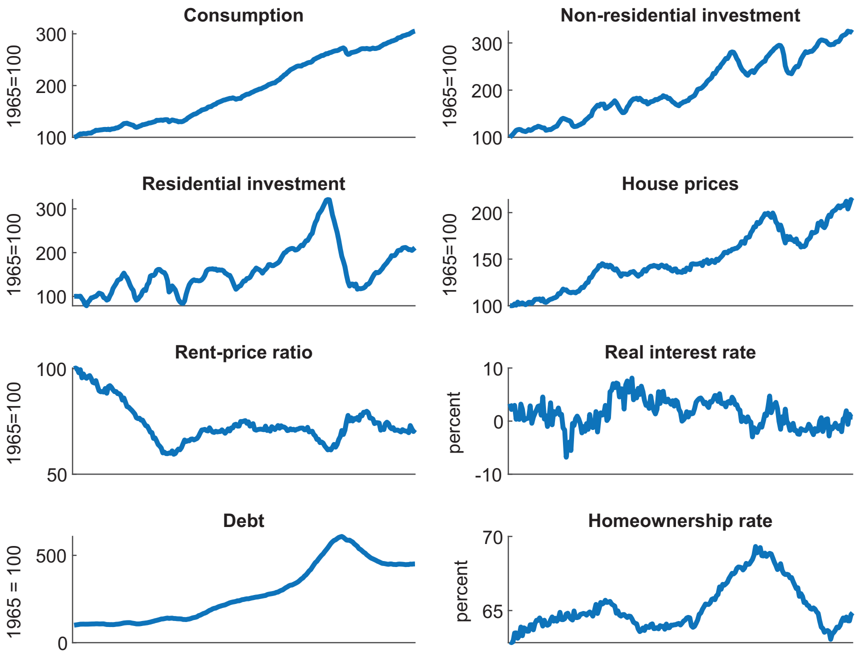

Figure 1. Data.
Notes: Data used for estimation. Period: 1965Q1–2019Q4. The plotted rent-price ratio and real interest rate are annualized. The construction of the series is detailed in Online Appendix C.

4. Model versus data

4.1. Data

We estimate our model using series for the following variables which are crucial for housing markets: house prices, the rent-price ratio, consumption, non-residential (i.e. capital) investment, residential investment (which corresponds to the output in the housing sector), private debt, interest rates, and homeownership rates. GDP is not included as it is the sum of residential investment (multiplied by house prices) and output in the rest of the economy.

We estimate our model from 1965 to 2019 with quarterly logged HP-filtered data (the smoothing coefficient is 1,600[28]). Following Pfeifer (2020), we use a one-sided HP filter.[29] For robustness, we repeat the exercise for the period 1965–2006. The latter period has the advantage of excluding the years of the Great Recession and thus significant non-linearities in housing markets such as the zero lower bound for interest rates, as well as significant variations in house prices and debt.

The choice of our data generalizes Iacoviello and Neri (2010) to account for rental markets and is detailed in Online Appendix C, which also details the construction of the series we use. Figure 1 shows the series (in levels) used for the estimation.

4.2. Parameters calibration

We calibrate β_1 so that the annual real interest rate is 3% [as in Iacoviello and Neri (2010) or Kaplan et al. (2020)]. β_2 is set to 0.98 in line with Hendricks (2007), and β_3 can assume any value as it does not play any role in the equilibrium equations. The same applies to ϕ. We only assume that β_3 and ϕ are low enough such that agent 3 is a renter in equilibrium (see Proposition 2). The steady-state value of the preference for housing, j_{ss}, is set to have a ratio of residential real estate over quarterly GDP of about 4 (its average between 1965 and 2016).

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Table 1. Calibrated parameters

Parameters	Values	Source/targets
β_1	0.99264	3% annual interest rate, Iacoviello and Neri (2010)
β_2	0.98	Hendricks (2007)
χ_1	1.11	$n_1 = 1/3$
χ_2	3.20	$n_2 = 1/3$
χ_3	3.25	$n_3 = 1/3$
j	0.07	Ratio residential real estate/ quarterly GDP 4%
ω_2	3.9204	10% of homeowners, Sommer et al. (2013)
ω_3	2.2440	66% homeownership rate, Sommer et al. (2013)
γ_c	0.3	Iacoviello (2005)
δ_c, δ_h	0.013925	Annual capital depreciation rate, Davis and Heathcote (2005)
α_h	0.7	Labor in construction, Iacoviello and Neri (2010)
γ_h	0.1	Iacoviello and Neri (2010)
δ_x	0.0048	Annual rent-price ratio of 4.9%
m	0.85	Iacoviello and Neri (2010)

The parameters driving the preference for leisure χ_1, χ_2 and χ_3 are set such that $n_1 = n_2 = n_3 = 1/3$. The underlying assumption is that agents of different types spend the same amount of time working at the steady state.

The relative shares ω_2 and ω_3 are calibrated to have a homeownership rate of 66.6% and so that landlords represent 10% of the homeowners, as in Sommer et al. (2013). This approach has the advantage of setting these parameters on clear empirical evidence without the need to use wealth holdings as a proxy, as in previous works in this literature. Indeed, wealth holdings data entail several measurement problems to calculate shares (see discussion in Justiniano et al. (2015) among others).

The quantity of aggregate land is normalized to 1. The parameter δ_x is such that the annual rent-price ratio is 4.9% (its average between 1965 and 2016). The corresponding annual depreciation rate for housing is about 1.8%, which is close to micro-estimates (e.g. Nakajima and Telyukova (2020) use a value of 1.7%). We set the loan-to-value ratio m to 0.85 as in Iacoviello and Neri (2010), and in line with Calza et al. (2013).[30]

We set γ_c to 0.3 in line with the literature [e.g. Iacoviello (2005)], and thus, α_c is set to 0.7. Following Iacoviello and Neri (2010), the land share and the capital share γ_h in the construction sector are both set to 0.1. The share of labor α_h is thus 0.8, in line with Iacoviello (2005). Capital depreciation is assumed to be the same in both sectors and $\delta_h = \delta_c = 0.0139$ in line with Davis and Heathcote (2005). Table 1 summarizes the calibration.

4.3. Parameters estimation

We estimate the persistence and standard deviations of the shocks that hit our economy, as well as capital adjustment costs.

Our list of shocks includes the technology shocks in the consumption and housing sectors, respectively [see equations (16) and (17)], the preference shock for housing [see equation (7)], the discount factor shock [see equation (4)], the homeownership shock [see equation (5)], and efficiency shocks in both sectors [see equation (9)].

Table 2 displays the priors and posteriors of the parameters we estimate. Our priors for the parameters driving the adjustment costs for capital in the two sectors (ϕ_c and ϕ_h) are based on Iacoviello and Neri (2010).

Table 2. Estimated parameters

		Posterior			
Parameter	Prior [mean,std]	Mean	Median	10%	90%
ϕ_c	gamma [10,2.5]	5.410	5.336	4.374	6.585
ϕ_h	gamma [10,2.5]	8.843	8.643	6.049	11.860
ρ_{A_c}	beta [0.8,0.1]	0.952	0.953	0.934	0.969
ρ_{A_h}	beta [0.8,0.1]	0.999	0.999	0.998	0.999
ρ_j	beta [0.8,0.1]	0.419	0.418	0.367	0.472
ρ_β	beta [0.8,0.1]	0.452	0.453	0.405	0.497
ρ_{Υ^c}	beta [0.5,0.2]	0.426	0.428	0.352	0.495
ρ_{Υ^h}	beta [0.5,0.2]	0.995	0.995	0.991	0.998
ρ_Ω	beta [0.5,0.2]	0.754	0.753	0.700	0.808
σ_{A_c}	invgamma [0.001,0.1]	0.006	0.006	0.006	0.007
σ_{A_h}	invgamma [0.001,0.1]	0.014	0.014	0.013	0.015
σ_j	invgamma [0.001,0.1]	0.030	0.030	0.028	0.032
σ_β	invgamma [0.001,0.1]	0.005	0.005	0.005	0.006
σ_{Υ^c}	invgamma [0.055,0.2]	0.051	0.050	0.039	0.064
σ_{Υ^h}	invgamma [0.055,0.2]	0.241	0.240	0.222	0.261
σ_Ω	invgamma [0.001,0.1]	0.009	0.009	0.008	0.010
corr($\epsilon_{Ac}, \epsilon_{Ah}$)	beta [0.0,0.3]	0.459	0.460	0.390	0.526
corr($\epsilon_j, \epsilon_\Omega$)	beta [0.0,0.3]	0.184	0.184	0.098	0.269

As Iacoviello and Neri (2010), the prior means and standard deviations of the persistence parameters are set to 0.8 and 0.1, except for those related to the marginal efficiency of investment, which are based on the priors used in Christiano et al. (2014), and for those related to the shock affecting the proportion of renters. For the latter, we chose a moderate value of 0.5 for the prior mean, with a relatively large standard deviation of 0.2.

Finally, we allow for a degree of correlation between the two productivity shocks and between the preference shock for owned housing units and the shock to the proportion of renters. We use diffuse priors for these correlations, with a prior mean of 0.

The posterior distributions are estimated using the Metropolis-Hastings algorithm.[31] Table 2 shows key statistics of these posterior distributions. In line with Iacoviello and Neri (2010), we find that technological shocks in the consumption and housing sectors are quite persistent. We also find that productivity innovations in the housing and consumption sector are positively correlated. As expected, housing preferences and the homeownership rate shocks, respectively, are also positively correlated.

We find a relatively high volatility for the shock on the marginal efficiency of investment in the housing sector, together with a relatively strong persistence. This is explained by the high volatility of residential investment observed in the data, to which the shock contributes significantly (see the analysis of moments and the one for the variance decomposition below).

Finally, we find that both intertemporal and intratemporal shocks to preferences are not very persistent. This comes from the fact that the real interest rate displays significant short-run volatility (see Figure 1). Similar considerations apply for the rent-price ratio, to which the intratemporal shock contributes significantly (see Figure 1 and Table 4).

Table 3. Baseline model, moments for period 1965–2019

		Baseline model	
	Data	1st order	2nd order
Std output	1.63	1.09	1.13
Standard deviations relative to output:			
House prices	1.59	1.52	1.62
Rent-price ratio	1.66	2.15	2.30
Consumption	0.84	0.73	0.71
Non-residential investment	2.79	3.20	3.17
Residential investment	6.94	8.56	14.54
Private debt	1.92	2.10	2.30
Interest rate	0.21	0.27	0.26
Cross-correlation between output and			
Consumption	0.92	0.79	0.75
Residential investment	0.69	0.35	0.36
Non-residential investment	0.70	0.77	0.75
House prices	0.52	0.12	0.07
Cross-correlation between house prices and			
Consumption	0.45	0.26	0.24
Residential investment	0.63	0.27	0.12
Rent-price ratio	−0.91	−0.58	−0.62
Interest rates	0.03	−0.19	−0.14

Notes: Data include series for the period 1965-2019. "1st order": predictions from the model simulated with a first-order approximation. "2nd order": predictions from the model simulated with a second-order approximation with pruning. Results come from a simulation of the model of a 30000-period length. The first 500 periods have been truncated. One-sided HP filter, lambda = 1600. Aggregates are expressed in *per capita* units.

4.4. Business cycle properties: model versus data

We now turn to the business cycle properties of our model when the parameters are set at their estimated posterior means.

Table 3 shows standard statistics of the main aggregates and prices of our model. The first column shows the statistics of our data for the interval 1965–2019. The second and third columns show the simulated moments by using first and second-order approximations of the model.[32] In the Online Appendix we also provide two robustness checks. First, we repeat the same exercise with shorter series (1965–2006) so as to exclude the Great Recession. Indeed, its aftermath featured unconventional monetary policies and non-linear trends in housing markets. Secondly, we repeat the same exercise by using alternative data for housing prices (using the FHFA house price index instead of the U.S. Census Bureau house price index on single-family homes).

We see that the relative standard deviations of our key variables of interest are very close to those in the data. The model reproduces the greater volatility of rent-price ratios with respect to house prices [see discussion in Dong et al. (2022)]. The model can also reproduce the fact that the volatility of residential investment is much greater than the one for non-residential investment. Moreover, by including renters, the share of collateral-constrained agents decreases and our model provides a relatively good match of debt volatility (for a discussion, see Guerrieri and Iacoviello (2017), who match debt volatility by introducing occasionally binding collateral constraints).

Analogously, the correlations predicted by the model are in line with the data and the literature. Our model does a particularly good job in reproducing the correlations between the variables representing agents's arbitrage when investing in housing, which is represented by equation (2).

Table 4. Variance decomposition simulating one shock at a time (in percent)

	ϵ_{Aht}	ϵ_{Act}	ϵ_{jt}	ϵ_{zt}	$\epsilon_{\Upsilon;ct}$	ϵ_{Υ^h}	$\epsilon_{\Omega t}$
GDP	22.86	57.39	0.08	0.25	10.25	5.71	1.95
House prices	13.45	13.22	0.03	5.73	0.90	64.69	0.06
Rent-price ratio	13.98	1.37	28.72	3.32	0.13	47.93	2.23
Consumption	18.68	71.23	0.08	0.06	3.56	0.77	2.19
Non-residential investment	10.68	37.81	0.03	0.46	43.63	6.92	0.89
Residential investment	9.47	0.02	0.01	1.17	0.01	85.03	0.02
Private debt	10.57	11.07	2.48	0.40	0.74	67.59	4.07
Interest rate	5.56	3.32	0.16	76.01	1.36	13.35	0.28

Notes: Results come from a simulation of the model of a 30000-period length. The first 500 periods have been truncated. Second-order approximation with pruning. HP filter, lambda = 1600. Aggregates are expressed in *per capita* units.

This confirms the importance of the main mechanisms at play in our model. While the correlation between house prices and rent-price ratios is in line with data in all samples, the one between house prices and interest rates improves significantly when we use shorter series excluding the Great Recession (see our robustness exercise in the Online Appendix). This should not surprise the reader as we do not model (unconventional) monetary policies and have thus a disadvantage in reproducing the series including the financial crisis. Our results are also consistent with Favilukis et al. (2017) who underline the role of large risk premia for returns throughout that period.

Our model slightly underestimates the correlation between house prices and consumption, because of the absence of nominal rigidities, but still delivers positive correlations.[33] However, for the same reason [see the discussion in Iacoviello and Neri (2010)] the correlations of residential investment with output and house prices are smaller than those in the data. This is not new in the literature and is in line with Favilukis et al. (2017), who also have difficulties in reproducing the correlation between output and house prices.[34]

Table 4 presents a brief inspection of the variance decomposition of our variables of interest. Technological shocks in both sectors are the key drivers of the dynamics of output and consumption. Technological shocks in the housing sector also have a strong impact on the rent-price ratio and house prices. Those in the consumption sector have also a large impact on non-residential investment and house prices. Discount rate shocks are necessary in our model for the dynamics of the interest rates and explain more than 3/4 of their volatility.

Finally, while investment shocks in the consumption sector explain a large share of the dynamics of capital investment and output, those in the housing sector explain large shares of the fluctuations of house prices, residential investment,[35] rent prices, private debt, and interest rates. Indeed, shocks affecting house prices are transmitted to rent-price ratios and interest rates because of the strong linkage in equation (2) and debt because of the collateral constraint.

5. Dynamic properties of the model

To highlight the mechanisms at the roots of our results, we now study the dynamic response of our model to standard macroeconomic shocks which are key for housing markets.[36]

5.1. Responses to a technological shock in the consumption-good sector

Following a positive technological shock in the consumption-good sector [an increase ϵ_{Act} in equation (16)], output and aggregate consumption increase, as expected (see Figure 2). Moreover, the model generates a positive response of capital investment in both sectors (see Figure 3). Absent adjustment costs, there would be a full shift of resources from one sector to the other [see Davis

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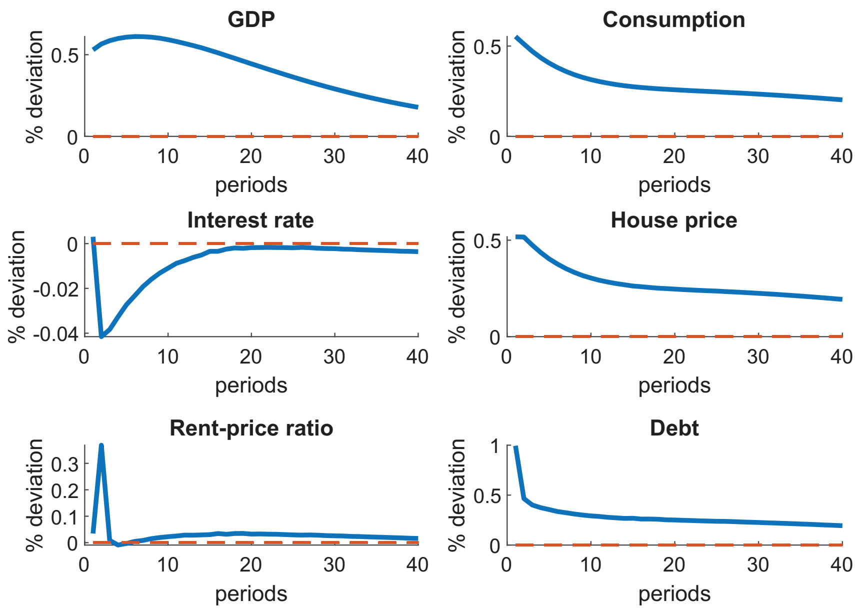

Figure 2. Responses to a technological shock in the consumption-good sector.
Notes: Simulated impulse response functions after a calibrated positive technological shock in the consumption-good sector. Aggregates are expressed in *per capita* units. Consistently with national statistics, aggregate consumption also includes housing services (relative prices are kept fixed).

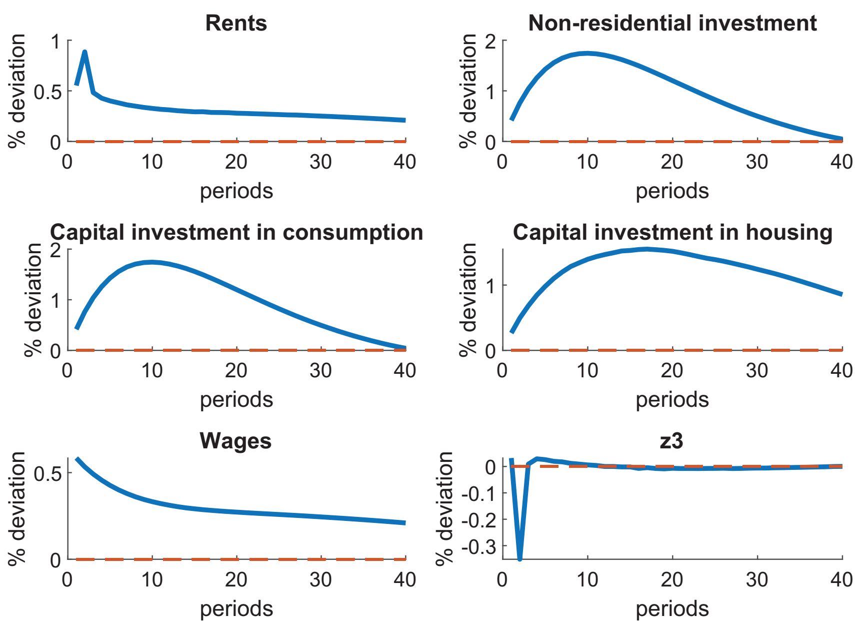

Figure 3. Responses to a technological shock in the consumption-good sector.
Notes: Simulated impulse response functions after a calibrated positive technological shock in the consumption-good sector. Non-residential investment is expressed in *per capita* units and is the sum of capital investment in the consumption-good sector and capital investment in the housing sector. z3 refers to rented units by agent 3.

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and Van Nieuwerburgh (2015)]. The presence of adjustment costs for sector-specific capital as well as the fixed supply of land (which effectively acts as an adjustment cost) prevents this type of effect, which would otherwise generate too much volatility of investment. Adjustment costs also play a role in the dynamics of the interest rate on loans because capital and financial returns are linked, and the former are affected by the fluctuations in the price of capital.

At the time of the shock (relative), house prices increase because the productivity in the housing sector falls with respect to the one in the consumption sector (see Figure 2).

As house prices increase, the value of the collateral of agents 2 rises, which relaxes their debt limit and enables them to borrow more (Figure 2). Agents of type 2 use these additional funds to increase non-durable consumption and lower their worked hours. This behavior is reinforced by an income effect associated to the increase in wages (Figure 3), which further dampens worked hours.

The interest rate dynamics are the result of the initial increase in the marginal productivity of capital in the consumption sector, the upward pressure due to the increase of credit demand from agents 2 and then their subsequent deleveraging. Since after the shock house prices stabilize, the rent-price ratio follows closely the dynamics of the interest rate because of the strong link in equation (2). The associated increase in rents explains why the demand of agent 3 for housing services decrease, even if their wage increases (see Figure 3).

5.2. Demand shocks for owned housing units

We now shift our attention to the effects of an *intratemporal* preference shock for owned housing [an increase in ϵ_{jt} in equation (7)]. According to Guerrieri and Iacoviello (2017), these shocks explain the "lion's share in the movement of house prices" and caused more than 70% of the decrease in consumption during the Great Recession.

The increase in j_t triggers a jump in housing demand of both agents 1 and 2. As expected, the demand shock pushes up house prices (see Figure 4), which is magnified by the fact that land is in fixed supply. The increase in demand also leads firms to produce more housing and allows our model to reproduce the positive correlation between house prices and residential investment observed in the data [see Iacoviello and Neri (2010)]. Collateral effects associated with the behaviors of agents of type 2 amplify the upward pressure on both house prices and residential investment and thus on total output.

As the calibrated shock has little persistence, the effect on house prices is short-lived. For agent 1, the direct effect of making housing consumption more attractive (relative to the consumption good) is dampened by an indirect one. Indeed, the short rise in house prices makes it worthwhile to sell housing in period 1 and generates a wealth effect. Agent 1 tradeoffs these two effects by increasing the share of his/her housing stock it consumes and by selling some of the housing stock it owns (which will only affect its housing consumption in the next period). The second effect together with the increase in resources associated with the wealth effect pushes up both non-durable consumption and saving, entailing a short-lived and small-sized decrease in interest rates.

Since the impact of the shock on interest rates is short-lived and interest rates come back quickly towards the steady state, the dynamics of the rent-price ratio essentially tracks the one of house prices [see equation (2)]. Therefore, in response to the demand shock for housing, house prices and rent-price ratios (together with nominal rents) increase. This is because the increased preference for housing services makes landlords less willing to rent to tenants. This pushes up rents and rent-price ratios. Notice also that if the preference shock also hit rented units, this effect would be magnified.

These underlying mechanisms highlight how the shock emphasized by Guerrieri and Iacoviello (2017) cannot reproduce the joint dynamics of housing prices and rents during the Great

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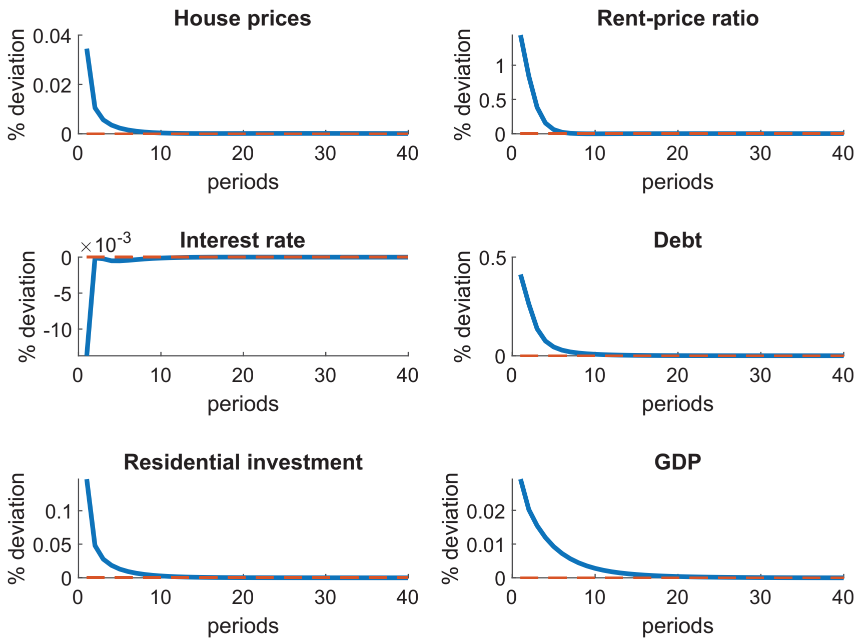

Figure 4. Responses to a preference shock for owned housing.
Notes: Simulated impulse response functions after a calibrated positive preference shock for owned housing. Residential investment refers to output in the housing sector while investment refers to capital accumulation in both sectors. Aggregates are expressed in *per capita* units.

Recession if we account for rental markets. Indeed, during the financial crisis, house prices have plummeted but rent-price ratios have increased.

6. Housing markets during Covid times

While the US economy was dramatically affected by the Covid-19 pandemic, its housing market experienced a boom. In particular, the following stylized facts characterized the US housing market after the outbreak of Covid (see Figure 5):

1. House prices rose substantially. This was the case for urban, suburban, and rural areas [see Zhao (2020)].[37]
2. Rent-price ratios decreased significantly. This trend was also present at a disaggregated level by accounting for housing quality [see the report of Joint Center for Housing Studies of Harvard University, JCHSHU (2020)].[38]
3. In response to the severity of the effects of the Covid pandemic, the Fed cut the reference interest rate to 0–0.25% in March 2020 and in June 2020 engaged to keep it low through 2022. This was transmitted to record-low mortgage rates [see JCHSHU (2020)].
4. Despite the fact that lending standard tightened, mortgage debt continued to rise. Moreover, the delinquency rate on mortgages did not significantly increase [JCHSHU (2020)].
5. Residential investment dropped in the second quarter of 2020 but went back to its pre-crisis trend in the third quarter. Notice also that the pre-crisis period featured several quarters of particularly strong growth in residential investment.

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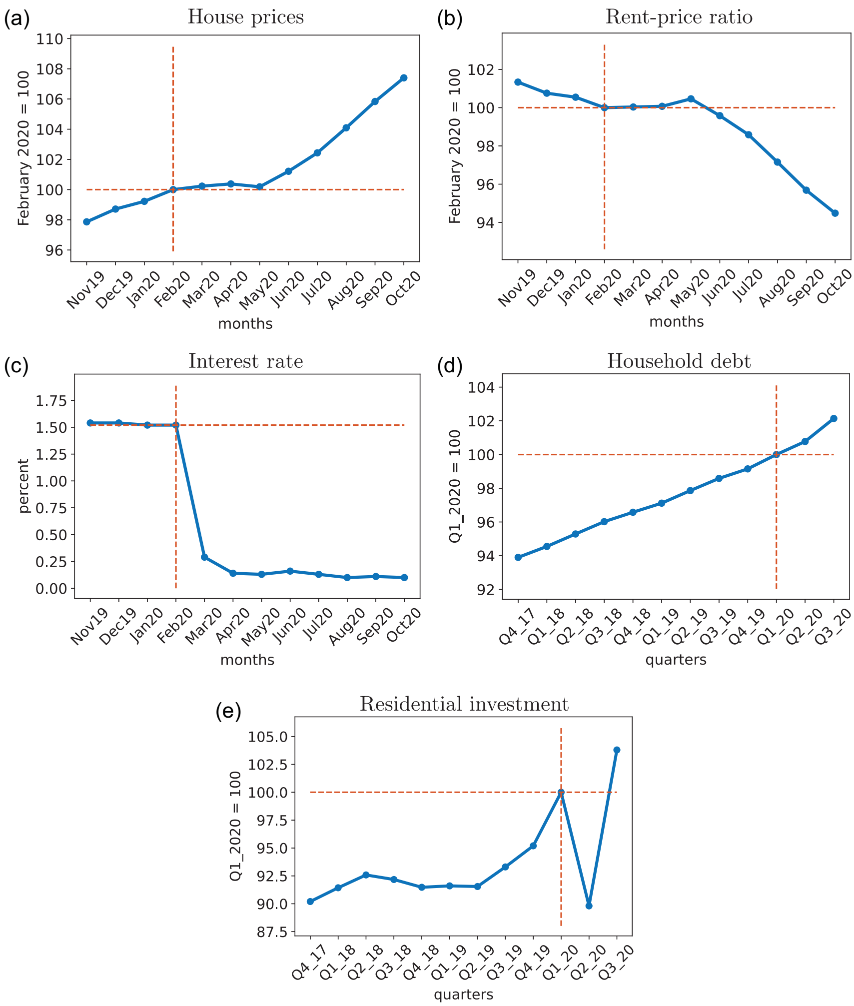

Figure 5. Housing trends during Covid times.
Sources: See Appendix C.3.

While the driving forces behind these facts are still debated, our simple model can serve as a useful tool to provide a better understanding of the underlying economic mechanisms. Indeed, its simple structure allows both to reproduce housing market dynamics and to track the transmission channels.

Supply factors were in the list of usual suspects because the Covid crisis strongly disrupted supply in many sectors. However, several considerations do likely dismiss supply shortages as main drivers of the trends in the months following the Covid outbreak. First, the fall in housing supply was very short and was preceded by a steady growth in residential investment (see Figure 5). Second, housing sales increased above the trend starting from summer 2020 [JCHSHU (2020)]. Finally, supply shortages can in principle explain the increase in house prices but they hardly rationalize the contemporaneous decrease of the rent-price ratio and interest rates.

Demand factors seem more probable drivers of the observed dynamics. The restrictions in response to the pandemic indeed imposed strong limits to consumption possibilities.[39] They particularly limited non-durable consumption while being less restrictive towards durable consumption. As a result, personal savings spiked.[40] The pandemic also imposed distance working

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and as many people were forced to spend more time at home, some started looking for bigger places to live.[41] These changes in behaviors share the common root of being *policy-induced changes in preferences*. Preference shocks have been extensively used in the housing macroeconomic literature and are commonly proxied by an *intratemporal* increase in the demand of housing over the one for non-durables [a shock on j_t in our model, see equation (7)] as studied in Section 5.2. Such shock is in line with an increase in house prices, debt, and residential investment. However, while triggering a substitution effect in favor of housing (especially for the agents who are not subject to the collateral constraint), it fails to explain the drop in the rent-price ratio. Indeed, an increase in the preference for housing over consumption drives up the relative price of housing consumption (i.e. rents). Alternatively, intertemporal changes in behaviors are proxied by *intertemporal* preferences shocks à la Guerrieri and Iacoviello (2017). These shocks introduce a tilt in agents' preferences for current vs future consumption (i.e. saving). They are thus consistent with the recent surge in personal savings and the massive change in consumers' behaviors emphasized by Goolsbee and Syverson (2021). In our model, they correspond to equation (4) and drive up the demand for tomorrow's consumption over today's one.

In what follows we argue that while the restriction-induced change in intratemporal preferences surely had some impact on the observed housing market dynamics, the tilt in intertemporal preferences induced by the restrictions has likely played a greater role. Indeed, as we show in the next section, a shock to intertemporal preferences is globally in line with all the patterns in Figure 5.

6.1. Responses to a pandemic-induced tilt in intertemporal preferences

We now calibrate the intertemporal preference shock of equation (4) so as to track the evidence in the aftermath of the Covid outbreak. Starting in Spring 2020, the Fed injected liquidity so as to cut interest rates. As a result, the (annualized) interest rate on 3-month T-bills went from about 1.50% in February 2020 to close to 0% in April 2020 (see Figure 5). The announcement of Jerome Powell on June 10th 2020 for the Fed to keep the funds rate between 0% and 0.25% throughout 2022 contributed to drive down long-term interest rates as well (e.g. the interest rate on 10-year treasuries went down by 0.84 percentage points during the same period).

We therefore pin down the persistence of the shock during the pandemic so that it mostly dies out after 3 years, which is globally in line with Powell's commitment. More precisely, we set ρ_β so that after 12 quarters the shock is only 5% of its initial value. As a result, $\rho_\beta = 0.05^{1/12} \simeq 0.78$. We then calibrate the standard deviation of $\epsilon_{\beta t}$ so that the initial decline in the quarterly interest rate is about 0.375 percentage points, consistent with the data.[42]

Figure 6 shows the response of the economy to the calibrated intertemporal preference shock, which is in line with the stylized facts highlighted in Figure 5.[43] The shock directly affects intertemporal decisions and thus hits the Euler equation of agents of type 1 (i.e. the dominant consumers). They choose to postpone current consumption of non-durable goods and housing services, while they supply more savings, labor and invest in housing (to rent). This is consistent with the strong jump in personal savings starting from March 2020. As agents of type 1 pin down the interest rate, this change in intertemporal behavior pushes the interest rate down. This also mimics the Fed's policy, that accommodated the surge of savings with large liquidity injections to stimulate the economy.

In equilibrium, these additional savings are associated with an increase of loans supplied to agents of type 2 and with an increase in capital in both sectors. As their intertemporal preferences are also modified, agents of type 2 also reduce their current consumption and accumulate more housing (and thus debt). Contrarily to the two previous ones, agents of type 3 solve a static problem and are not *directly* affected by the shock, although their behaviors are impacted by the change in equilibrium prices.

The shock we consider in this section thus tracks both the large rise in aggregate savings *and* the decrease in the interest rate. The implied increase in the demand for housing, from both agents

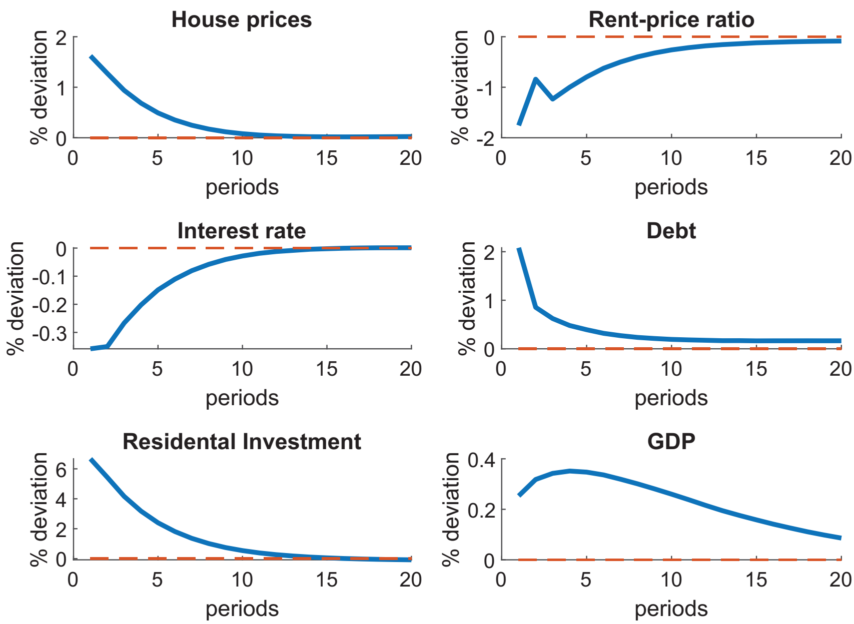

Figure 6. Responses to a shock to intertemporal preferences.
Notes: Simulated impulse response functions after a calibrated shock to intertemporal preferences. Debt is expressed in *per capita* units.

1 and 2, pushes house prices up. Importantly, this does not translate into an increase in rents. In contrast, the rent-price ratio decreases. This is due to the fact that agents of type 1 are supplying more housing on the rental market. It explains why agents of type 3 are consuming more housing services and less non-durables.[44] Notice finally that the effect of the pandemic-induced shock is amplified by housing markets, who drive up both residential investment (i.e. housing output) and aggregate GDP.

The relationship between interest rates, housing prices, and the rent-to-price ratio is clearly characterized by equation (2). It shows that the interest rate is strongly linked with the product of housing prices and the rent-price ratio. Following a shock that reduces the interest rate, a rise in housing price is associated with a decline in the rent-price ratio [see the results of the SVAR of Dias and Duarte (2019)]. The return on housing investments is in this case positively correlated with the interest rate.

6.2. Housing-induced welfare effects

The exercise in the previous section has highlighted that the policy-induced change in intertemporal preferences has had an expansionary impact on the housing market. We now shift our attention to its heterogeneous welfare implications, depending on agents' statuses in the housing market.[45]

Welfare is simply defined here as an agents' instantaneous utility.[46] We measure welfare changes as follows. Let us denote by $u_i(\cdot)$ the instantaneous utility of agent i, which is given by

$$u_i\left(c, hs, n\right) = \ln c + j_{ss} \ln hs - \chi_i \frac{n^\eta}{\eta} \tag{21}$$

where c is consumption, hs are housing services and n are hours worked. Let us denote by $u_{i,ss}$ the value that this function takes at the steady state with

$$u_{i,ss} = u_i\left(c_{i,ss}, hs_{i,ss}, n_{i,ss}\right) \tag{22}$$

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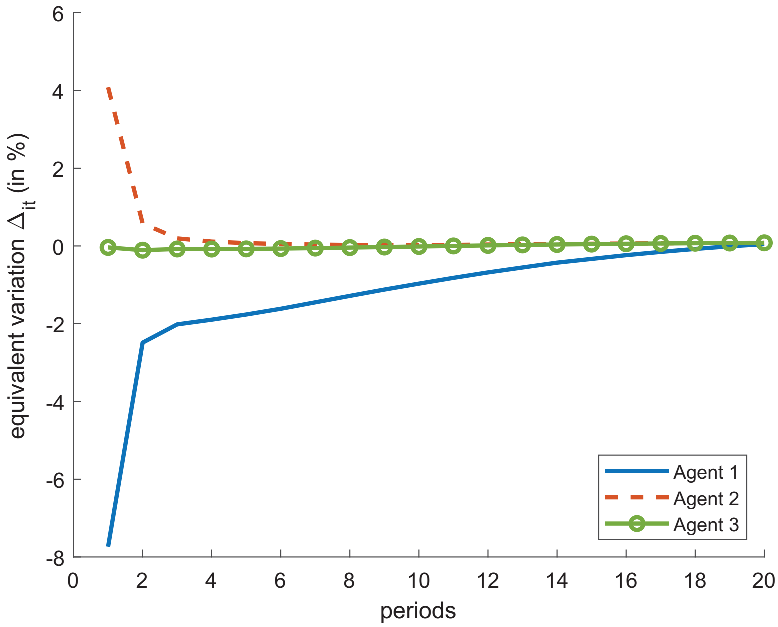

Figure 7. Welfare effect of the intertemporal preferences shock.
Notes: Simulated impulse response functions after a calibrated intertemporal preference shock. IRFs represent percent deviations from the steady state of instantaneous utilities of agents of type 1, 2, and 3, respectively.

We aim at grasping the change in welfare in response to the intertemporal preference shock. To this purpose, we proxy by Δ_{it} the instantaneous welfare change relative to the steady state where:

$$u_i\left(c_{it}, hs_{it}, n_{it}\right) = u_i\left(c_{i,ss}\left(1+\Delta_{it}\right), hs_{i,ss}\left(1+\Delta_{it}\right), n_{i,ss}\right) \tag{23}$$

Hence, Δ_{it} is a consumption-equivalent variation measure. A positive Δ_{it} indicates that instantaneous utility in t is higher than in the steady state (and vice versa), and the welfare change is expressed in percentage of the steady-state consumptions of non-housing goods and housing.[47]

Figure 7 plots the response of agents' changes in (housing and goods) consumption-equivalent losses or gains in response to the shock. Notice in particular that the shock has a large negative impact on the welfare of landlords. This is because of a negative *direct* effect on non-durable consumption and labor supply, that is associated with the tilt in preferences (due to an increase of landlords' labor supply and a decrease in consumption). But there is also a significant *indirect* effect of the shock, that is transmitted to their welfare via their revenues. Indeed, because of the fall in interest rates and the associated one in rents, landlords experience a significant decrease in financial revenues (see Figure 8). In contrast, the welfare of renters is barely affected. Indeed, the fall in rent-price ratios partly compensates for the decrease in wages and thus the fall in renters' incomes. Finally, the fall in interest rates drives down credit costs, benefiting borrowers.

Contrarily to the common view, our analysis suggests thus that policies entailing lower interest rates have particularly weighted on landlords although lower interest rates have contributed to drive up the value of housing (and the wealth of homeowners). Our framework shows how low rates can be beneficial to lower-income households, who rent and borrow.

There is thus an important channel linking agents' welfare with the role they play on housing markets because of heterogeneous financial revenues. In our model, this is due to changes in rents and interest rates. As remarked by Pereira Da Silva,[48] because "households at the bottom of the distribution are renters, the middle class owns mainly real estate and bank deposits, and those at

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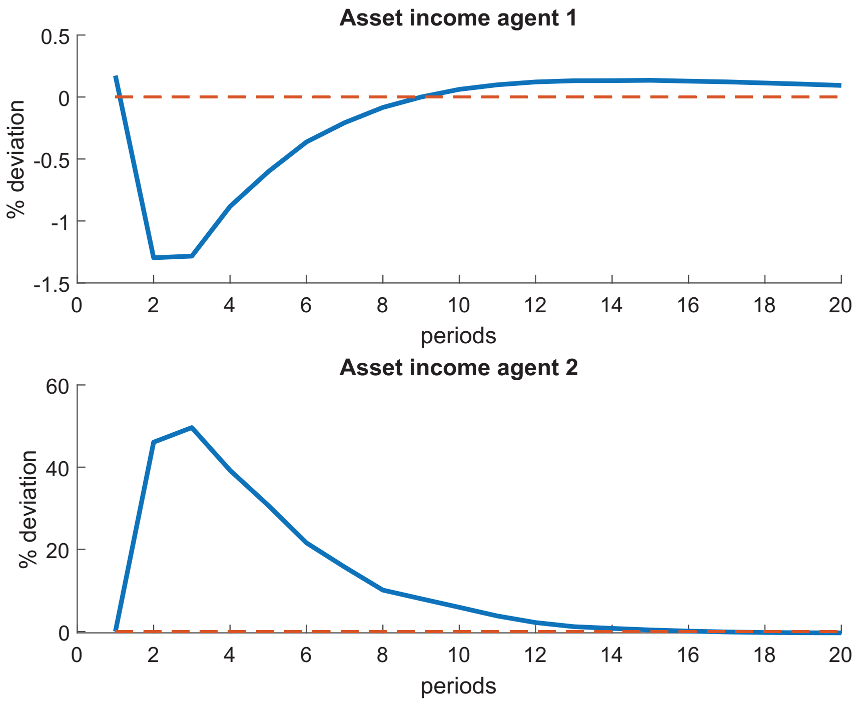

Figure 8. Asset income and interests on debt.
Notes: Simulated impulse response functions after a calibrated intertemporal preference shock. IRFs represent percent deviations from steady state of asset income for agent 1 (first panel) and for agent 2 (second panel). The assets income of agent 1 is: $p_t\left[l_t-\delta_x\right]h_{1t}x_{1t-1}+r_t^ck_{t-1}^c+r_t^hk_{t-1}^h+p_t^ql_t^qq_{t-1}-\left(R_{t-1}^d-1\right)d_{1t-1}$, consistently with Propositions 1 and 2. The assets income of agent 2 is: $-\left(R_{t-1}^d-1\right)d_{2t-1}$.

the top own more sophisticated (and higher-yielding) financial assets," monetary expansion seems to increase wealth inequality.

The debate is far from being closed and recent evidence points instead in favor of a decrease of inequality when the monetary policy is expansionary.[49] While the evaluation of the distributional effects of current policies is beyond the scope of our work, our results contribute to the debate by pointing out the importance of the social stratification induced by the housing market. Our parsimonious framework helps clarifying the heterogeneous impacts of low-interest rate policies on households depending on the role they play on housing markets.

7. Conclusions

This paper proposes a model that explicitly distinguishes real estate and housing rental markets. We provide theoretical foundations for introducing rental markets within standard DSGE models with infinitely lived agents and borrowing constraints. In our framework, the behavior of agents that are heterogeneous with respect to their housing status allows to determine endogenously both housing and rental prices. In equilibrium, the rent-to-price ratio is tightly linked to interest rates through an arbitrage condition, which is at the roots of the main economic mechanisms at play. We estimate a quantitative version of our model with standard Bayesian methods to match the US data of the last decades. The model is able to explain and reproduce the main stylized facts featuring the aftermath of the Covid-19 outbreak. The model also allows for welfare comparisons

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and suggests that the housing-rich agents, namely the landlords, are those who are paying the most for the impact of Covid-induced policy shocks.

This research can be extended in various directions. In particular, our theoretical results can justify introducing rental markets in a large class of DSGE models. One natural avenue would be to allow for nominal rigidities. This is of particular interest as rent prices are a significant component of consumer price indices [see e.g. Hazell et al. (2020)]. This would also allow us to study the impact of monetary policies. Including the market for business real estate and its relation with the housing market would also be of interest as remote working might increase as a consequence of the pandemics. As young households tend to be renters and older ones owners, age considerations could also give a more complete picture of real estate and rental markets. We leave these extensions for further research.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/S136510052300055X

Notes

1 Wong (2008) provides empirical evidence on a decline in house prices in Hong Kong following the outbreak of SARS and finds both direct and indirect effects of the epidemic. Francke and Korevaar (2021) provide past evidence on both (small) rent-price decreases and a (dramatic) fall in house prices following outbreaks of the plague in 17th-century Amsterdam and cholera in 19th-century Paris.
2 Among many others, Favara and Imbs (2015) emphasize the importance of introducing debt while studying housing dynamics.
3 Following Kiyotaki and Moore (1997) and Iacoviello (2005), we focus on a local analysis around the steady state, where rental markets are here an endogenous outcome.
4 In the New Keynesian literature, some exceptions are Rubio (2019) and Mora-Sanguinetti and Rubio (2014) among others.
5 In Iacoviello and Pavan (2013), they are assumed to be exogenous.
6 See also Sommer and Sullivan (2018) for an analysis of housing policies in a similar framework.
7 Search and matching frictions are also used to track flows from renting to homeownership and explain housing price fluctuations. However, while focusing on housing quality features, this literature abstracts from credit markets (see Ngai and Tenreyro (2014), among many others).
8 In a model with segmented housing markets, Alpanda and Zubairy (2016) introduce a framework where some agents can (exogenously) only have access to housing services by renting them while other agents only by buying them. Similarly, Greenwald and Guren (2021) introduce heterogeneity within a category of agents to obtain fractional homeownership. In their model, borrowers' decisions to own/rent depend on a distribution of idiosyncratic surplus characterizing each of them.
9 Otherwise, when all variables are endogenously determined, the introduction of rental markets generally leads debt-constrained agents to rent in equilibrium so that collateral constraints are no longer binding and become irrelevant.
10 An important advantage of our simple model is that it is easily solved with usual perturbation methods. In particular, other models that feature a rental market (see, for instance, Kiyotaki et al. (2011), among many others) are usually solved with global methods. Due to the curse of dimensionality, the number of predetermined variables must be limited, which potentially neglects important aspects.
11 The analysis of housing trends in response to the developments following the war in Ukraine is beyond the scope of this work. This would require to use a model accounting for the role of inflation and monetary policies, consistently with nowadays rich literature as in Calza et al. (2013) among many others.
12 As remarked by d'Albis and Iliopulos (2013), the introduction of rental markets entails some technical problems. When all variables are endogenously determined, all impatient agents generally hold no debt or housing assets and buy housing services from patient agents on the rental market.
13 Notice that the timing convention for hs_{it} implies that at each time t agents live in and extract housing services from the housing stock accumulated in previous periods. This activity entails a depreciation of the housing stock and only the remaining units can be resold (see description of the second constraint below). Notice that this timing assumption is consistent with the one of standard production functions as only previously accumulated capital can be used for production and it depreciates during the production activity. (see the full model in the sections below).
14 Limit cases are studied in the literature. The case with $\phi = 1$ corresponds to a perfect rental market studied by d'Albis and Iliopulos (2013). The case with $\phi = 0$ corresponds to the standard setting with no rental market, as in Iacoviello (2005). We exclude them here to reduce the length of the proofs.
15 $(1 - \phi)$ is akin to an iceberg transport cost as is often considered in the trade literature.

16 Several papers allow for $\phi < 1$ within life-cycle frameworks as Kiyotaki et al. (2011) and Iacoviello and Pavan (2013). The novelty of the analysis here is to show that in a framework with infinitely lived agents, $\phi < 1$ can lead to an economy with both renters and indebted homeowners.
17 Notice, however that, because of the imperfection in the rental market, the effective rent paid by a renter for one unit of housing services is $p_t l_t/\phi > p_t l_t$.
18 The benchmark model in what follows will be based on this endogenous partition and borrows from the data the shares of the different types of agents.
19 In equilibrium, the collateral constraint is binding and the interest rate is set by the dominant consumer. Indebted agents would thus choose to borrow more (i.e. save less) in the absence of down payment requirements.
20 In Sun and Tsang (2017), Rubio (2019) among others, renters, and owner-occupiers are proxied by one only agent (the representative borrower consumes a composite of rented and borrowed housing at the same time). One of the disadvantages of such a framework is that it does not allow to focus on (welfare) heterogeneous effects of shocks, depending on agents' housing status (see the discussion in what follows).
21 Demography is an obvious factor. See Iacoviello and Pavan (2013) among many others, who introduce rental markets in an overlapping generation model.
22 Notice that l_{t+1} is the counterpart of the traditional formula defining the user cost of capital.
23 We remind the reader that Propositions 1 and 2 imply that in equilibrium owner-inhabitants do participate to the credit market and the real estate market but are not players in the rental market. In contrast, tenants do not access credit nor real estate markets but are active players in the rental market.
24 See also the macroeconomic literature studying the dynamics around the zero lower bound, where these shocks have been extensively used. We can also interpret them here as a way to mimic the effect of monetary policy shocks. Monetary policies are otherwise not modeled here.
25 Our analysis focuses on the "intensive margin" of households' decisions. Households' housing status depends on their degree of impatience, as above showed. In order to account for fluctuations in homeownership, we introduce a stochastic shock hitting the share of renters in the population. Its distribution is estimated in what follows. In a similar vein, Greenwald and Guren (2021) introduce a distribution of benefits to landlord and borrowers' ownership to reproduce the data on varying homeownership.
26 In previous versions of the paper, we also experimented the introduction of adjustment costs for housing. That version of the model had more difficulties in matching some key correlations and also implied additional terms in equation (2), making the main mechanisms less transparent.
27 Following Iacoviello and Neri (2010), we choose not to incorporate LTV shocks into our baseline model. This is because LTV shocks contribute little to match house price fluctuations and generate too much debt volatility. There is no clear consensus in the literature on the role played by LTV shocks. Several works suggest that shocks hitting collateral constraints are not key drivers of housing market dynamics [e.g. Justiniano et al. (2019), Kiyotaki et al. (2011), or Sommer et al. (2013)]. In contrast, in Favilukis et al. (2017) and Garriga et al. (2019) LTV shocks are main drivers of housing dynamics. Kaplan et al. (2020) stress how the presence of a rental market implies that fewer agents are credit-constrained, which limits the effects of collateral shocks. We thus borrow their view and provide a robustness check with a version of our model with LTV shocks in the Online Appendix.
28 We use a value of 1,600 for the parameter of the one-sided HP filter. This is in line with the one commonly used for the standard two-sided HP filter for business cycle analysis with quarterly data [Ravn and Uhlig (2002)]. For recent examples, see Born and Pfeifer (2021), Clemens et al. (2023), Harding and Klein (2022).
29 We use the matlab codes by Meyer-Gohde (2010) based on the procedure in Stock and Watson (1999). Table D.4 in the Online Appendix provides a robustness check with a standard two-sided HP filter. Although the two filters give rather similar results, it should be noted that the two-sided HP filter is not recommended for Bayesian estimation [see Pfeifer (2020)]. That is why our baseline uses a one-sided HP filter.
30 This entails a steady state level of debt to quarterly GDP of about 1.45, which is smaller than its average between 1965 and 2019 (a period which includes the high debt increases prior to the Great Recession), but still globally in line with data.
31 The model is solved and estimated using Dynare [version 5.3, see Adjemian et al. (2023)]. For the estimation, we use a first-order approximation of the model around the deterministic steady state. Codes are available upon request.
32 For the second-order approximation, we use a pruning algorithm [for a discussion about pruning, see Andreasen et al. (2017)].
33 The sizes of technological shocks seem to play a significant role in it, see the following discussion on the variance decomposition.
34 Matching correlations of both house prices and rent-price ratios with output remains challenging. For instance, Favilukis et al. (2017) reproduce well the correlation between output and the price-rent ratio but overestimate significantly the correlation between house prices and output (which likely contributes to the positive correlation between the rent-price ratio and output in their model). Our model is not perfect in that respect either, although, as we have highlighted, it is quite successful in generating the main correlations underlying equation (2).
35 Notice that this shock significantly helps in matching the volatility of residential investment. If we had to rely on technology shocks only, their larger required size would entail a counterfactual negative correlation between house prices and residential investment and/or consumption in absence of nominal rigidities.

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36 IRFs refer to a second-order approximation of the model with pruning.
37 Housing prices increased also for the vast majority of US cities included in the S&P/Case-Shiller 20-City Composite Home Price Index.
38 Rent-price ratios also decreased at an urban, suburban, or rural level. This is consistent with past evidence on rent-price ratios following outbreaks of the plague in 17th-century Amsterdam and cholera in 19th-century Paris [see Francke and Korevaar (2021)]. Rents generally decreased too—with some exceptions [see Gupta et al. (2022)]—so that they stagnated on average. Having said that, since the rise in house prices was more significant, the decrease of rent-price ratios is confirmed.
39 Goolsbee and Syverson (2021) decompose the observed massive change in consumers' behavior into the direct effect of the restrictions themselves and the fear induced by the latter or by the propagation of the pandemic throughout the region. In this work, we do not enter into the details of this discussion and we denote the impact on consumers' behavior as "policy-induced changes in preferences."
40 In March 2020, personal savings jumped to levels that were more than six times greater than pre-crisis ones. In January 2021 personal savings were still 4 times greater pre-crisis savings. See https://fred.stlouisfed.org/series/PMSAVE.
41 In some cases, many households decided to flee the cities. The above focus on rural vs urban house prices and rent-price ratios suggests that the fleeing-to-rural areas phenomenon is not the dominating force.
42 The 5-year forward inflation expectation rate went from 1.65% in February 2020 to 1.30% in March 2020 (see https://fred.stlouisfed.org/series/T5YIFR). Thus, expected real interest rates went initially down by less than nominal ones. However, inflation expectations surpassed their February 2020 level in August 2020; thus, expected real interest rates then went down more that nominal ones. This suggests that, over the whole period, the decline in the nominal and real interest rates was very similar. This is particularly the case in light of generalized very low inflation levels. For simplicity, the decline in the real interest rate (of our model) is set in our exercise so as to be the same as the decline of the nominal interest rate observed in the data. More in particular, we match the observed fall in nominal interest rate with the average of the fall of real rates in our model during the first two periods.
43 In this exercise, we focus on the shock that in our view is the most significant in explaining recent trends. This allows us to go into the deep of the underlying mechanisms. A better fit of the data would obviously require to consider a realistic combination of shocks, based on empirical evidence.
44 Notice that the labor supply of agents of type 1 increases and wages are pushed down so that the revenues of agent 3 decrease.
45 A full study of Covid's welfare impact on different types of households is beyond the scope of this work because it would require to analyze the heterogeneous effect of the pandemic on the job market, as documented in many recent empirical works. We here implicitly assume that income losses are compensated by expansionary fiscal policies.
46 This allows us to isolate utility from the discount rate shock itself, which would be otherwise taken into account if we computed the discounted sum of the flow of utilities.
47 With only one good, it is trivial to isolate welfare changes through consumption-equivalent variations, while it might be complicated by the presence of multiple consumption goods. In the current setting with two goods (consumption and housing services), the computation is simplified by the fact that households adjust both consumption and housing services by the *same* factor. Indeed with the log-log utility function we use the ratio of consumption and housing services is always constant for a given relative price. Therefore, it makes sense to adjust consumption and housing services by the same to assess welfare effects.
48 "Monetary policy, technology and inequality," Peterson Institute for International Economics roundtable: "Central banking and inequality: Covid-19 and beyond," 11 December 2020, Centre for Economic Policy Research - International Monetary Fund.
49 Coibion et al. (2017) study the effects of monetary policy shocks on consumption and income inequality. Even if their focus is not explicitly on wealth, by studying consumption they document some of the different channels through which monetary policy shocks affect inequality. Based on household-level micro-data, they provide evidence in support of the distributional effects of monetary policies. They also find that contractionary shocks raise inequality while expansions mitigate it. More recently, Hohberger et al. (2020) compare the distributional effects of Taylor rules and quantitative easing within an estimated open-economy DSGE model. Their model considers both hand-to-mouth and dynamically optimizing agents with access to bonds and equity and accounts thus explicitly for some form of financial wealth. They show how expansionary monetary policies, both in the form of Taylor rules and quantitative easing, tend to mitigate income and wealth inequality between the two population groups.

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