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Trend growth expectations and U.S. house prices before and after the crisis

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Abstract:
We provide an analysis that might help distinguish rationally justified movements in house prices from potentially non-rational movements, using a two-sector business cycle model, in which investment in housing is subject to collateral constraints. A large portion of the evolution of U.S. house prices during the past 20 years can be reproduced when expectations of future income growth as published in surveys are used as an input into the model. Changes in growth expectations translate into corresponding changes in house prices, since the value of housing must be linked to expected aggregate income. Only since about 2005 do actual and model-implied house prices clearly diverge, calling for explanations not based on economic fundamentals.

Keywords:
House prices, trend growth, Kalman filter, real-time data, borrowing constraints.

JEL-Classification:
E13, E32, D83, O40.

Non-technical summary

The collapse of the housing markets since 2007 in a number of advanced economies, notably the U.S., Ireland and Spain, had enormous economic repercussions, not least because of the interaction between house prices and housing finance. Finding strategies to avoid a repetition of the excesses in borrowing during the preceding upswing and thus the costs in terms of employment and income during the 2008 - 2009 economic meltdown is high on the agenda of economic policy makers. One prerequisite for this is to understand the role of house price movements. Most research has argued that some departure from rational expectations on the part of home buyers is needed to understand house price dynamics before the crisis.

In this article, we aim at examining more carefully the information actually available to agents when they were forming expectations about future house prices. Our point of departure is that the fundamental driver of aggregate house prices are expectations of future income available to buy housing. In turn, income growth is largely determined by productivity growth. Crucially, the trend component of productivity growth can only be imperfectly observed so that, ultimately, house prices must be driven by what is perceived to be the long-run growth rate. Consequently, capital gains in housing markets should be largely determined by changing expectations of such macroeconomic fundamentals.

We develop a real stochastic growth model of a small open economy where investment in physical capital by entrepreneurs and purchases of housing by a subset of households is subject to collateral constraints. To operationalize changing expectations of trend growth, we assume that observed productivity consists of two components with different persistence. Agents cannot observe these two components separately and therefore have form estimates about the persistent component of productivity growth. We approximate these estimates by survey measures of growth expectations as published by the Survey of Professional Forecasters or Consensus Forecasts.

Using those empirically documented changes in trend growth expectations, our model is capable of explaining a significant portion of the evolution in real U.S. house prices from 1991 to 2009. Thus much of the increase in house prices during that period may well be consistent with a rational response to changing perceptions of aggregate long-run growth, and is therefore fundamentally justified. Models with only temporary changes in productivity about a trend path would not capture these movements.

From a policy perspective it would be desirable to develop some measure of fundamentally justified house prices so as to aid regulatory institutions in identifying potential risks of misvaluations. The lesson from our analysis seems to be an optimistic one: our approach potentially allows to distinguish fundamentally justified changes in house prices from those driven by irrationality or bubbles. The only basis are observed house prices and con-currently observed measures of growth expectations from surveys, and a sufficiently rich model linking such measures. Of course, the substantial degree of uncertainty of estimates of trend growth implies similarly a high degree of uncertainty around the level of house prices that, according to our model, is fundamentally justified.

Nicht-technische Zusammenfassung

Der Zusammenbruch der Immobilienmärkte seit 2007 hatte in entwickelten Volkswirtschaften, insbesondere den U.S.A., Irland, und Spanien, enorme realwirtschaftliche Auswirkungen, nicht zuletzt aufgrund der Interaktion zwischen Hauspreisen und Hausfinanzierung. Für wirtschaftspolitische Entscheidungsträger ist es nun eine wesentliche Priorität, Strategien zu finden, die eine Wiederholung der exzessiven Kreditaufnahme im vorangehenden Aufschwung, und damit auch Verluste an Beschäftigung und Einkommen wie während der Krise 2008 und 2009, vermeiden. Es ist daher von hoher Bedeutung, die Ursachen und Rolle von Hauspreisveränderungen zu verstehen. Ein Großteil der wirtschaftswissenschaftlichen Forschung argumentiert hier, dass für eine Erklärung der Hauspreisdynamiken vor der Krise eine Abkehr von der Annahme rationaler Erwartungsbildung auf Seiten der Hauskäufer nötig ist.

In diesem Aufsatz untersuchen wir, wie die zur Verfügung stehenden Informationen der Marktteilnehmer deren Erwartung über zukünftige Hauspreisentwicklungen beeinflussen. Unsere Arbeit zeigt, wie Erwartungen über zukünftige aggregierte Einkommen die individuelle Entscheidung zum Hauskauf beeinflusst, da sie auf die aggregierte Hauspreisentwicklung rückwirken. Das gesamtwirtschaftliche Einkommenswachstum wiederum ist im wesentlichen vom Wachstum der Produktivität bestimmt. Allerdings lässt sich die Trendkomponente des Produktivitätswachstums nur unvollkommen beobachten, so dass, letztendlich, Hauspreise von der Wahrnehmung der langfristigen Wachstumsrate bestimmt sein müssen. Daher werden auch Preisänderungen in Immobilienmärkten größtenteils von sich ändernden Erwartungen über solche makroökonomische Fundamentaldaten abhängig sein.

Wir entwickeln ein reales stochastisches Wachstumsmodell einer 'kleinen' offenen Volkswirtschaft in dem Investitionen in physisches Kapital und der Kauf von Häusern eines Teils der Haushalte Kreditbeschränkungen in Form von Sicherheiten unterliegen. Um sich ändernde Erwartungen des Trendwachstums im Modell darzustellen, wird unterstellt, dass die beobachtbare Produktivitätsänderung aus zwei Komponenten unterschiedlicher Persistenz besteht. Marktteilnehmer können diese Komponenten nicht getrennt beobachten und müssen daher über die Entwicklung der persistenten Komponente des Produktivitätswachstums Schätzungen bilden. Als Annäherung für diese Schätzungen ziehen wir Maße aus Umfragen über Wachstumserwartungen, wie sie vom Survey of Professional Forecasters oder Consensus Forecasts veröffentlicht werden, heran.

Mit Hilfe der so dokumentierten Änderungen in den Trendwachstumserwartungen kann das Modell einen wesentlichen Anteil der Entwicklung der realen U.S. Hauspreise von

1991 bis 2009 erklären. Daher scheint ein großer Teil des Anstiegs der Hauspreise während dieses Zeitraumes konsistent mit einer rationalen Reaktion auf sich verändernde Wachstumserwartungen zu sein, und damit auch fundamental gerechtfertigt. Modelle, die nur transitorische Änderungen der Produktivität um einen konstanten Trendpfad abbilden, würden diese Hauspreisbewegungen nicht erklären.

Aus wirtschaftspolitischer Sicht wäre es wünschenswert, ein Maß von fundamental gerechtfertigten Hauspreisen entwickeln zu können, um damit Regulierungsbehörden zu helfen, potentielle Risiken von Fehlbewertungen zu identifizieren. Der hier vorgestellte Modellierungsansatz hat das Potential, fundamental gerechtfertigte Hauspreisschwankungen von solchen zu unterscheiden, die von Irrationalität oder Blasen getrieben sind. Die Grundlage hierfür wären beobachtete Hauspreise und die verfügbaren Maße von Wachstumserwartungen, sowie ein hinreichend spezifiziertes Modell, das diese Maße theoretisch verknüpft. Natürlich impliziert die erhebliche Unsicherheit der Schätzung des Trendwachstums auch eine hohe Unsicherheit bezüglich des Niveaus der nach unserem Modell fundamental gerechtfertigten Hauspreise, so dass es nur Teil einer aus vielen Indikatoren gewonnenen Risikoeinschätzung sein würde.

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1 Introduction

The collapse of the housing markets since 2007 in a number of advanced economies, notably the U.S., Ireland and Spain, had enormous economic repercussions, not least because of the interaction between house prices and housing finance. Finding strategies to avoid a repetition of the excesses in borrowing during the preceding upswing and thus the costs in terms of employment and income during the 2008 - 2009 economic meltdown is high on the agenda of economic policy makers. One prerequisite for this is to understand the role of house price movements. On the one hand, house prices and housing investment may be largely driven by rationally formed beliefs about the relevant fundamentals. Then home purchases by households and bank' willingness to provide the necessary funds should in principle not be questioned. If, on the other hand, beliefs about fundamentals are in some sense irrational, then it may be necessary to devise policies that correct the resulting behavior in housing markets. Figure 1 shows a number of measures of the unprecedented run-up in house prices that preceded the crisis, and the subsequent collapse.

Most research has argued that some departure from rational expectations on the part of home buyers is needed to understand house price dynamics before the crisis. From an asset pricing perspective, the observed increase in price-to-rent ratios during the boom phase can in principle be justified either by a decline in the discount rates with which future rental income is being discounted, or by the anticipation of future capital gains. To generate the latter, some form of extrapolative expectations about future house prices has been suggested (Shiller, 2007; Adam, Kuang, and Marcet, 2011). While Case and Shiller (2010) argue that survey expectations from recent home buyers support the assumption of extrapolative expectations, their results may suffer from sample selection bias. In fact, forecasts of house price growth from other sources display less momentum than found by Case and Shiller.[2] Adam et al. (2011) explain house-price dynamics by a learning

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[2]For example, even during the peak appreciation year of 2005, when nationwide house prices were increasing by more than 11%, the forecast of the Mortgage Bankers Association for median existing home price growth during the second and third calendar year ahead did not exceed 4% per year, or 2% house

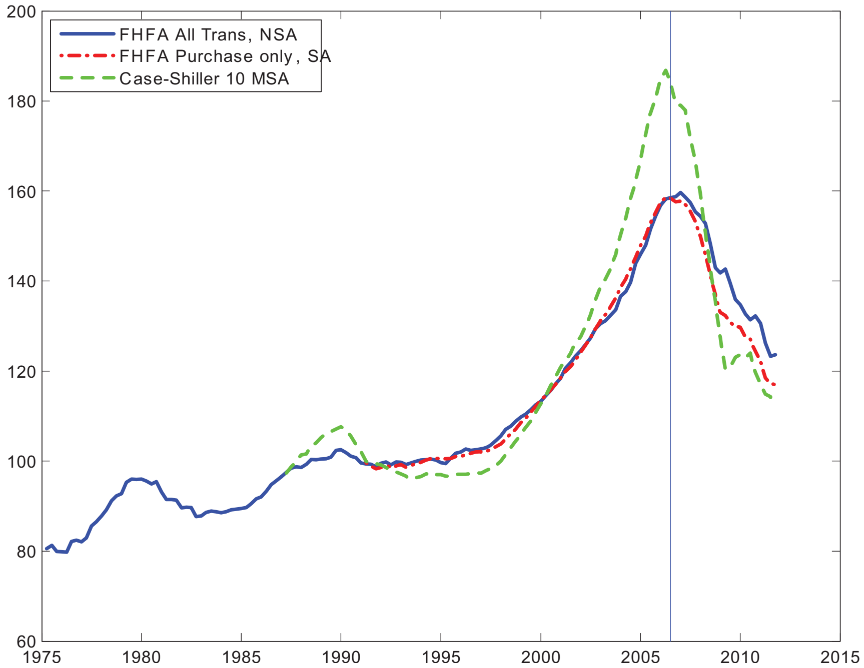

Figure 1: U.S. Real House Prices

Notes: All house price indices are deflated with the GDP deflator. The vertical line denotes the second quarter of 2006, when real prices peaked.

mechanism in which households form expectations that are governed by a perceived law of motion for house prices which ex-post is confirmed by the actual law of motion.

This paper, too, focuses on the role of expectation formation for explaining the recent housing boom-and-bust episode. However, rather than discarding up-front the discipline imposed by rational expectations, we aim at examining more carefully the information actually available to agents when they were forming expectations about future house prices. Our point of departure is that the fundamental driver of aggregate house prices are expectations of future income available to buy housing. In turn, income growth is largely determined by productivity growth. Crucially, the trend component of productivity growth can only be imperfectly observed so that, ultimately, house prices must be driven by what is perceived to be the long-run growth rate. Consequently, capital gains in housing markets should be largely determined by changing expectations of such macroeconomic fundamentals.[3]

We develop a real stochastic growth model of a small open economy where investment

price growth in *real* terms. We thank Zeno Enders for pointing us to the MBA forecasts.

[3] Of course, many other factors contributed to the bubble in housing such as innovations in mortgage securitization or lax underwriting practises in mortgage originations.

in physical capital by entrepreneurs and purchases of housing by a subset of households is subject to collateral constraints as in Iacoviello (2005). The small open economy assumption serves here as a useful approximation of the openness of U.S. capital markets. To operationalize changing expectations of trend growth, we assume that observed productivity consists of two components with different persistence, where one shock, the "growth rate shock," raises (or reduces) the *growth rate* of technology persistently above (or below) its steady-state level, whereas the other leads to a permanent increase merely in the *level* of technology without, however, any persistent effects on its growth rate. Agents cannot observe these two shocks separately and therefore are assumed to have formed estimates about the persistent component of productivity growth. The key step in our analysis is to approximate these estimates by survey measures of growth expectations as published by the Survey of Professional Forecasters or Consensus Forecasts.

We find that, using empirically documented changes in trend growth expectations, our model is capable of explaining a significant portion of the evolution in real house prices from 1991 to 2009. Thus much of the increase in house prices during that period may well be consistent with a rational response to changing perceptions of aggregate long-run growth, and is therefore fundamentally justified. Models with only temporary changes in productivity about a trend path would not capture these movements.[4] During the run-up to the financial crisis, long-horizon survey expectations of productivity growth actually increased markedly over the period 1997 to 2003, coinciding with the early years of an accelerated increase in housing, and have declined since 2005.[5] However, from 2005 onward, real house prices continued increasing at a higher pace than predicted by the model, reached a peak in about 2006, and later undershoot the model's prediction. It appears that it is potentially fruitful to allude to notions of irrationality, but in our view only for this particular episode.

Our paper emphasizes that changes in growth expectations can have a significant effect on house prices. To better understand the driving forces in the model, we present one possible mechanism that generates long-run growth expectations in the presence of imperfect information. Namely, we use the Kalman filter to derive an optimal growth forecast from observed changes in productivity. Even though this filter only uses a fraction of the information available to professional forecasters, one can show that Kalman- filtered productivity growth rates actually coincide with a large portion of the changes in growth forecasts from surveys.[6] Then we conduct an impulse response analysis in the model,

[4] See, for example, Davis and Heathcote (2005).
[5] For more detailed discussion, see Hoffmann, Krause, and Laubach (2011).
[6] Again, see Hoffmann et al. (2011) and Edge, Laubach and Williams (2007).

comparing the dynamic adjustments of productivity and housing market variables under imperfectly and, the hypothetical, perfectly observed changes in growth trends. Finally, in the context of this particular learning algorithm, we discuss how to think about changes in growth expectations driven by non-fundamental forces, or even bubbles.

From a policy perspective, the explanations discussed above (and others) imply different desirable policy responses. To be clear, we do not claim that changes in housing finance practices or extrapolative expectations had no role to play. While recognized shortcomings in housing finance are currently being addressed by regulatory and supervisory measures, it is less clear how the implications of fundamental uncertainty about trend growth rates highlighted in this paper can be mitigated. But it would of course be desirable to also develop some measure of fundamentally justified house prices so as to aid regulatory institutions in identifying potential risks of misvaluations. From this perspective, the lesson from our analysis seems to be an optimistic one: our approach potentially allows to distinguish fundamentally justified changes in house prices from those driven by irrationality or bubbles. The only basis are observed house prices and con-currently observed measures of growth expectations from surveys, and a sufficiently rich model linking such measures. According to our model, signs of misvaluation emerge around the beginning of 2005. That said, the substantial degree of uncertainty around estimates of trend growth implies similarly a high degree of uncertainty around the level of house prices that, according to our model, is fundamentally justified.

Our paper is related to several strands of literature. In the combination of housing investment and borrowing constraints, our model builds on Iacoviello (2005). In his model as in ours, "patient" households provide funding to "impatient" households and to entrepreneurs, who are subjected to collateral constraints. The collateral offered to patient households by impatient households to obtain loans consists of housing. In Figure 2, we present some prima facie evidence on the aggregate role of housing as collateral, motivating its inclusion in our model. The solid line is the ratio of households' mortgage debt relative to their disposable personal income (at annual rate). This can be interpreted as a measure of household leverage. While this ratio has trended up over most of the post-1975 sample, between early 1999 and its peak in early 2008 it doubled, and has only declined modestly since then. By contrast, the ratio of household mortgage debt to the market value of owner-occupied real estate remained essentially unchanged up until the peak of (real) house prices in mid-2006, when it started rising sharply as a result of the decline in the denominator. This flat "average loan-to-value" ratio masks substantial redistribution from seasoned home owners, whose LTVs fell as their home values appreciated, to new mortgage borrowers, especially those in the subprime segment, whose LTVs rose during the boom (Mayer et al., 2009).[7] Nonetheless, it is striking that the enormous increase in household indebtedness evident from the solid line was on average not associated with an increase in the ratio of debt outstanding to collateral value.[8]

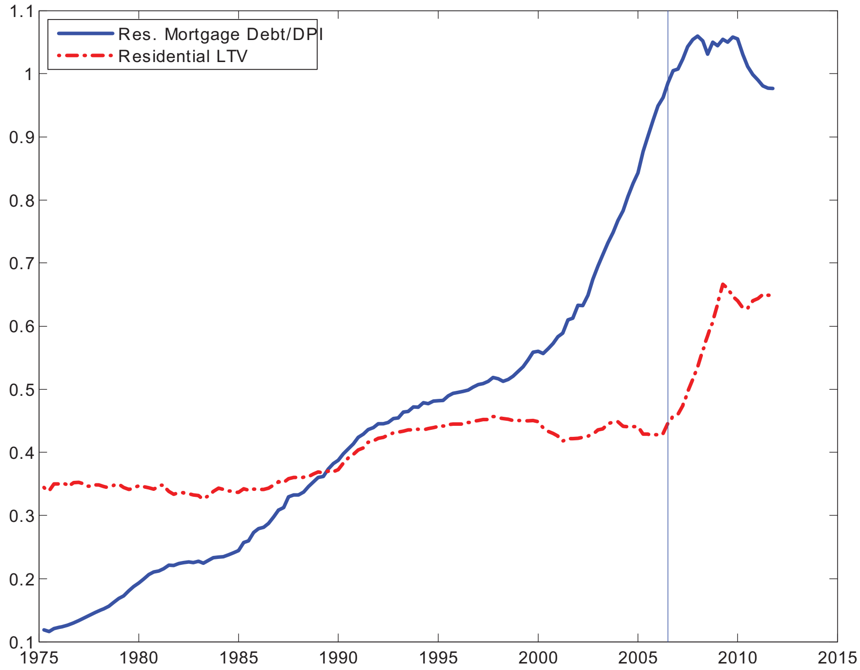

Figure 2: Household Leverage and LTV Ratios

Notes: The solid line presents home mortgage liabilities of households and nonprofit organizations divided by disposable personal income. The dash-dotted line shows home mortgage liabilities of households and nonprofit organizations divided by the market value of households' owner-occupied real estate. The vertical line denotes the second quarter of 2006, the peak of real house prices.

Our model is different from Iacoviello's in that we abstract from nominal rigidities as we focus on the effects of low-frequency movements in perceived trend growth. On the other hand, to account for the secular trend in real house prices, we employ a two-sector model in which technology in the housing sector is assumed to grow more slowly than

[7] See also MacGee (2009).

[8] One aspect that has received substantial attention is the structure of housing finance, especially innovations related to the subprime mortgage market. There is some evidence supporting the view that the incentives of mortgage originators under the "originate-to-distribute" model to properly screen mortgage applicants were severely impaired, facilitating the origination of loans that were more likely to default than might have been apparent to purchasers of these loans in secondary markets (Keys et al., 2010; Calem et al., 2010). Alternatively, certain aspects of automated loan applications may not have been correctly priced by investors (Bubb and Kaufman, 2011). While these innovations help explain how certain borrowers were able to obtain financing as the boom continued, a related question is why home buyers, including those in the prime segment of the mortgage market, were willing to continue to buy houses despite the unprecedented runup in house prices, shown in Figure 1.

that in the non-housing sector.[9] Also in contrast to Iacoviello, we assume that housing capital is being accumulated by patient households, part of which is sold to impatient households, whereas non-housing capital is being accumulated and used in production by entrepreneurs. Allowing for the accumulation of housing seems important because we need to explain the run-up in housing prices *despite* the concomitant construction boom. In these respects there are similarities to the model by Davis and Heathcote (2005).

As discussed before, the paper's second key addition are the assumptions about the technology process and the information structure. The model of learning about trend growth is based on Edge, Laubach, and Williams (2007). The paper perhaps most closely related to ours is Kahn (2008), who uses an alternative information structure concerning trend growth based on Kahn and Rich (2007). However, Kahn (2008) does not consider any role for financial frictions and the resulting borrowing constraints in explaining housing price movements, a feature that we highlight in our analysis. On a more fundamental level, our study is related to work on the determinants of asset prices, such as Barsky and DeLong (1993), who show the close link between long-run dividend growth expectations and share prices. The same logic applies to our model.

The paper proceeds as follows. In section 2 we introduce the model on which we base our analysis, discuss the solution method and present the calibration. In section 3 we first simulate the model with historical productivity data and information on perceived growth rates. Then we present the impulse response analysis. Section 4 offers a summary and policy conclusions.

2 The model

Our model is a two-sector stochastic growth model, with one sector producing goods for consumption and investment in non-housing capital and the other producing residential investment (or construction more generally).[10] We combine this two-sector structure with a setup in which there is borrowing and lending in steady state between different types of agents and the assumption of collateral constraints for investment in non-housing and housing capital, in the spirit of Kiyotaki and Moore (1997). Because the persistent technology shocks that are the focus of our analysis have strong real interest rate effects

[9] One interpretation of this structure is the use of land in the production of housing and the nearly fixed amount of desirable residential land, as emphasized by Davis and Heathcote (2007).

[10] Our choice of a two-sector model is intended to capture the secular trend in the price of housing relative to the GDP deflator visible in Figure 1. From the beginning of the FHFA series in 1975 until 2011, this relative price increase averaged 1.2 percent per year; excluding the boom-and-bust decade, the average relative price increase between 1975 and 1999 was 1 percent.

that are counterfactual from the perspective of the U.S. experience since the mid-1990s, we use an open-economy model with an exogenously-assumed interest rate path in the rest of the world to dampen these effects somewhat. This is admittedly a shortcut, but one that is necessary as long as we do not wish to model the factors that have contributed to unusually low global real interest rates since the early 2000s.

As noted before, besides the two-sector structure there are two other notable differences between our model and that of Iacoviello (2005). First, our model features a stochastically varying trend growth rate, in addition to the familiar variations in the level of technology. This element is crucial as it has the power to generate large swings in asset values which are difficult to obtain in standard models. Secondly, aggregate housing supply is endogenous, rather than fixed, and therefore responds to changes in growth expectations.

2.1 Households

Households are either borrowers or lenders. Patient households have a high discount factor, and thus are willing to provide funds at equilibrium interest rates, while impatient households have a low discount factor, and thus demand funds at the prevailing interest rate. Both types accumulate housing using a construction investment good produced by entrepreneurs. Households derive utility from a Cobb-Douglas aggregate of housing and consumption goods, and from leisure. In factor markets, they provide labor services to the production of consumption and housing goods conducted by entrepreneurs.

Patient households (denoted by $'$) maximize the present value of utility flows, discounted at factor β'

$$\sum_{t=0}^{\infty} \beta'^{t} \frac{\left[(C'_t)^{\iota} \, (H'_t)^{1-\iota} \left(1 - \frac{\chi}{1+\nu} L_t'^{(1+\nu)} \right) \right]^{1-\sigma} - 1}{1-\sigma}$$

where C'_t is consumption of goods and H'_t of housing, and $0 < \iota < 1$ is a weight. Labor supply L'_t enters utility negatively, with weight χ, and labor supply elasticity ν. The intertemporal elasticity of substitution is given by $1/\sigma$.

The patient households are the owners of the housing sector which accumulates residential structures by purchasing investment goods for construction from the entrepreneurial sector.[11] Patient households use H'_t units of housing for their own purposes, and sell H''_t

[11] This simplification is without loss of generality and similar to the treatment of capital accumulation in growth and business cycle models. It is straightforward to decentralize the housing sector and have households be the shareholders of real estate developers, who sell housing to households.

units to the impatient households. Total housing supply H^s_{t-1} evolves according to

$$H^s_t = (1-\delta)H^s_{t-1} + \frac{I_{h,t}}{n'}\left[1 - \frac{\phi_h}{2}\left(\frac{I_{h,t}}{I_{h,t-1}} - e^{g_h}\right)^2\right]$$

where H^s_{t-1} is the given stock in period t, as it is a state variable. A quadratic adjustment cost is scaled by ϕ_h and penalizes construction investment growth faster than the rate g_h of productivity growth in the housing sector. The total supply of housing must equal aggregate housing demand in period t, so that

$$H^s_{t-1} = H'_t + \frac{n''}{n'}H''_t$$

with H''_t impatient households' demand, and where n'' and n' are, respectively, the impatient and patient households' measures of size relative to the entrepreneurial sectors. Thus, the housing investment good $I_{h,t}$ produced by entrepreneurs is divided across n' patient households accumulating housing.

Maximization of utility is subject to the budget constraint

$$\begin{aligned} & W_t L'_t + B'_t + B^*_t + Q^H_t \frac{n''}{n'} H''_t \\ = \quad & C'_t + P_{h,t}\frac{I_{h,t}}{n'} + R_{t-1}B'_{t-1} + R^*_{t-1}B^*_{t-1} + Q^H_t \frac{n''}{n'} H''_{t-1}(1-\delta) \end{aligned}$$

where W_t is the competitive wage paid by entrepreneurs, $-B'_t$ is lending, which pays an interest rate R_t next period. $Q^H_t \frac{n''}{n'} H''_t$ is the revenue from selling H''_t housing units at price Q^H_t. The investment good for housing construction, $I_{h,t}$, is bought at the real price $P_{h,t}$ relative to consumption goods. There is a perfect resale market for houses, so that the un-depreciated stock of housing is available for repurchase in the next period. The depreciation rate is δ. Finally, patient households also have access to international capital markets, where they can borrow or save at an interest rate R^*_t. Foreign assets enter negatively, so that $-B^*_t$ is equivalent to net foreign assets.

Impatient households have a lower discount factor than patient households $\beta'' < \beta'$, and maximize utility

$$\sum_{t=0}^{\infty} \beta''^t \frac{\left[(C''_t)^{\iota}\,(H''_t)^{1-\iota}\left(1 - \chi L''^{(1+\nu)}_t\right)\right]^{1-\sigma} - 1}{1-\sigma},$$

but have only imperfect access to financial markets. By virtue of their lower discount factor , they have an incentive to borrow. They face a collateral constraint that limits the amount of borrowing to a fraction of their stock of housing:

$$B''_t \leq m'' E_t \left[\frac{Q''_{t+1} H''_{t+1}}{R_t} \right] \tag{1}$$

where Q''_{t+1} is the marginal value of a unit of installed housing. That is, borrowing B''_t cannot exceed a fraction m'' of the discounted value of housing $\left(Q''_{t+1} H''_{t+1}\right)/R_t$. The m'' is the degree to which housing wealth is collateralizable.[12] Holding m'' constant in our simulations is plausible, given the fairly constant value of the loan-to-value ratio shown in Figure 1.

The budget constraint faced by the households is

$$W_t L''_t + B''_t = C''_t + R_{t-1} B''_{t-1} + Q''_t \left(H''_t - H''_{t-1}(1-\delta)\right)$$

where $Q''_t \left(H''_t - H''_{t-1}(1-\delta)\right)$ is the value of the change in the stock of housing that impatient households choose to hold. It is the cost incurred when changing the stock. Also for impatient households, housing is assumed to depreciate at rate δ. Labor supply is rewarded at the same competitive wage W_t as for patient households. Thus labor is homogeneous, in contrast to the model by Iacoviello (2005).

2.2 Entrepreneurs

There is a continuum of entrepreneurs in the economy, represented by an agent maximizing

$$\sum_{t=0}^{\infty} \beta^t \frac{(C^e_t)^{1-\sigma} - 1}{1-\sigma}$$

subject to a budget constraint

$$Y_t + B^e_t = C^e_t + R_{t-1} B^e_{t-1} + W_t L_t + I_t$$

where Y_t is income from production, and B^e_t borrowing by the entrepreneur, who also have a discount factor lower than that of patient households, i.e., $\beta < \beta''$. For the entrepreneur, $W_t L_t$ is the wage bill paid to households, with $L_t = n' L'_t + n'' L''_t$, and I_t is investment in capital. Income is the sum of production of the investment and consumption goods, and of the construction good, $I_{h,t}$, sold at real price $P_{h,t}$ to patient households:

$$Y_t = C_t + I_t + I_{h,t} P_{h,t}$$

In turn consumption goods are the sum of consumption of the different agents, $C_t = C^e_t + n' C'_t + n'' C''_t$.

[12] See Iacoviello (2005) for discussion.

To produce, the entrepreneur uses capital and labor in two production facilities, called sectors. One sector produces the *normal, or non-housing,* consumption and capital investment goods, according to

$$Y_{n,t} = (Z_t L_{n,t})^{1-\alpha} K_{n,t}^{\alpha}$$

where subscript n denotes the capital and labor inputs in the normal goods sector, and Z_t is the level of technology. The other sector produces the construction investment good, according to

$$I_{h,t} = \left[(Z_{h,t} L_{h,t})^{1-\alpha} K_{h,t}^{\alpha}\right]^{\zeta} \mathcal{L}^{1-\zeta}$$

which combines capital and labor inputs with the available stock of land, $\mathcal{L}$. The subscript h denoting the *housing* goods sector, and $Z_{h,t}$ the sector specific technology. In equilibrium, factor inputs must add up to the total amounts of the factor available, i.e., $K_t = K_{h,t} + K_{n,t}$ and $L_t = L_{h,t} + L_{n,t}$. The stochastic processes for the technologies are specified presently.

Capital obeys an accumulation equation similar as that for the housing goods,

$$K_{t+1} = (1-\delta)K_t + I_t \left[1 - \frac{\phi}{2}\left(\frac{I_t}{I_{t-1}} - e^g\right)^2\right]$$

with an adjustment cost function centered around the steady state growth rate of investment, g. Because of borrowing constraints, the entrepreneurial sector's borrowing must not exceed a given fraction m^e of the market value of debt, thus obeying the constraint

$$B_t^e \leq m^e E_t \left[\frac{Q_{t+1}^K K_{t+1}}{R_t}\right] \tag{2}$$

where Q_t^K is the marginal value of capital.

2.3 Aggregate constraints and technology

To give an accurate description of the U.S. housing market, we cannot ignore the availability of international financial capital on which firms and households can draw. There, we take as our starting point that U.S. agents can borrow from abroad at a given interest rate, so for the purposes of our analysis the U.S. is a small open economy. Otherwise, households would be constrained by domestically available resources only, which leads to implausible interest rate and output dynamics.

Adding up the budget constraints of households and entrepreneurs results in the condition that all domestic borrowing or lending must equal the amount of foreign lending or borrowing. That is,

$$n'(B_t' + B_t^*) + n'' B_t'' + B_t^e = 0,$$

where B_t^* then evolves according to

$$B_t^* - B_{t-1}^* = \frac{1}{n'}\left(Y_t - C_t - I_t - I_{h,t}P_{h,t}\right) - (R_t^* - 1)B_{t-1}^*,$$

which is scaled by $1/n'$, since the patient households is the agent who, by assumption, has access to international financial markets. Because we treat the world interest rate as exogenous, we must specify a process for the international interest rate faced by households, R_t^*. We assume that R_t^* is proportional to a constant world interest rate $\overline{R}$, but with a differential that depends on the U.S. net foreign asset position. Specifically,

$$R_t^* = \overline{R} - \phi_R \left[\frac{B_t^*}{Y_t} - \frac{\overline{B}^*}{Y}\right],$$

where $\overline{B}^*$ is the long-run steady state net foreign asset position, which we assume to be zero. This formulation ensures that net foreign assets in the long run return to steady state, which in turn guarantees existence of a rational expectations equilibrium.

Technology in the non-housing sector and in the housing sector follow similar processes, evolving according to

$$\ln Z_t - \ln Z_{t-1} = g_t + \omega_t$$

and

$$\ln Z_{h,t} - \ln Z_{h,t-1} = g_{z_h,t} + \omega_{z_h,t}$$

where the growth rates follow the stochastic processes

$$g_t = (1 - \rho_g)g + \rho_g g_{t-1} + \eta_t \tag{3}$$

and

$$g_{z_h,t} = (1 - \rho_g)g_{z_h} + \rho_g g_{t-1} + \eta_{ht}$$

where the $\eta's$ and the $\omega's$ are i.i.d. random variables. The assumption of changing growth *rates* is crucial for the mechanics of the model, since they potentially introduce large and long-lasting variations in the present value of income, which is the ultimate source of the value of housing and capital. However, they render the model as it is non-stationary, as all most variables have a growth trend. Furthermore, the technologies in the two sectors as assumed to grow at potentially different rates in steady state, with g the growth rate of Z_t and g_{z_h} the growth rate of Z_{ht}.

2.4 Optimality conditions

The optimality conditions to the problems specified above are as follows. The intertemporal consumption decision of the patient household is guided by the real gross interest rates according to the Euler equation

$$1 = E_t \beta' \frac{\Lambda'_{t+1}}{\Lambda'_t} R_t$$

where the marginal utility is given by

$$\Lambda'_t = \left[(C'_t)^{\iota} (H'_t)^{1-\iota} \left(1 - \frac{\chi}{1+\nu} L_t'^{(1+\nu)} \right) \right]^{1-\sigma} \iota C_t'^{-1}. \tag{4}$$

The Euler equation shows the intertemporal trade off between current utility and future utility.

Investment in housing is guided by the dynamics of the real marginal value of a unit of installed housing accumulated by patient households, which in turn is the present value of all future flows of consumption relative to housing:

$$Q'_t = E_t \beta' \frac{\Lambda'_{t+1}}{\Lambda'_t} \left[\frac{1-\iota}{\iota} \frac{C'_{t+1}}{H'_{t+1}} + Q'_{t+1}(1-\delta) \right],$$

which gives the trade-off between consuming more housing today versus consuming more tomorrow. At the same time, the optimal amount of housing units sold to the impatient households must obey

$$Q''_t = \beta' \frac{\Lambda'_{t+1}}{\Lambda'_t} (1-\delta) Q''_{t+1} + \frac{1-\iota}{\iota} \frac{C'_t}{H'_t},$$

which gives the trade-off between giving up a unit of housing today and foregoing current consumption versus consuming more housing tomorrow. Obviously, the price of housing in the outside market and the shadow value of housing to the patient households will follow very similar patterns.

The optimal investment in housing units by the patient household is given by

$$\begin{aligned} P_{h,t} \quad = \quad & Q'_t \left[1 - \frac{\phi_h}{2} \left(\frac{I_{h,t}}{I_{h,t-1}} - e^{g_h} \right)^2 - \phi_h \left(\frac{I_{h,t}}{I_{h,t-1}} - e^{g_h} \right) \frac{I_{h,t}}{I_{h,t-1}} \right] \\ & + E_t \beta' \frac{\Lambda'_{t+1}}{\Lambda'_t} Q'_{t+1} \phi_h \left(\frac{I_{h,t+1}}{I_{h,t}} - e^{g_h} \right) \frac{I^2_{h,t+1}}{I^2_{h,t}} \end{aligned}$$

which smooths adjustment costs over time. While the equation for Q'_t above can be seen as representing the value of a unit of housing to the household, the optimality condition for housing investment shows how investment behavior ought to optimally respond to changes in the value. Finally, the labor supply condition is

$$W_t = \frac{\chi}{\iota} C'_t \frac{L_t'^{(\nu)}}{1 - \frac{\chi}{1+\nu} L_t'^{(1+\nu)}}.$$

For impatient households, the Euler equation must take into account the collateral constraint:

$$1 = E_t \beta'' \frac{\Lambda''_{t+1}}{\Lambda''_t} R_t + \eta''_t$$

where η''_t is the real shadow value of the borrowing constraint, and the marginal utility following the analogon to condition (4). Given R_t, the higher this shadow value (the more 'binding' it is), the smaller must be the expected growth in marginal utility, or the higher growth in consumption and housing (weighted by labor disutility). In other words, the impatient households, who would like to consume more today, and thus have a flatter consumption path than patient households, because of $\beta'' < \beta'$, is forced by the borrowing constraint to have a steeper consumption path.[13]

Optimal purchases of housing units must obey an equation similar to that of the patient household, again with the exception of the value of the borrowing constraint.

$$Q''_t = \beta'' \frac{\Lambda''_{t+1}}{\Lambda''_t} Q''_{t+1}(1-\delta) + \frac{C''_t}{H''_t} \frac{1-\iota}{\iota} + \eta''_t m'' \frac{Q''_{t+1}}{R_t}.$$

The impatient household, who would like to borrow funds to consume more housing services, at the optimum perceives the incentive to accumulate housing as higher because having more housing today relaxes the borrowing contraint tomorrow. Finally, the constraint itself must be binding in equilibrium, so that equation (1) holds with equality. The labor supply conditions for impatient households is exactly analogous to that of the patient.

For entrepreneurs, the marginal utility of wealth equals the marginal utility of consumption, $\lambda_t = (C^e_t)^{-\sigma}$, and the Euler equation is corrected for the value of the borrowing constraint, which affects the incentives to invest in capital

$$1 = \beta \frac{\Lambda_{t+1}}{\Lambda_t} R_t + \eta^e_t$$

and the marginal value of a unit of capital is given by the present value of all future marginal returns to using capital in production, r^K, corrected for the value of the constraint of borrowing.

$$Q^K_t = \beta \frac{\Lambda_{t+1}}{\Lambda_t} \left(Q^K_{t+1}(1-\delta) + r^K_{t+1} \right) + m\eta_t E_t \left[\frac{Q^K_{t+1}}{R_t} \right]$$

[13] For the sake of the illustration, we abstract here from the housing and labor variables also entering marginal utility.

The relationship between the marginal value of an installed unit of capital and investment is governed as before by

$$\begin{aligned} 1 &= Q_t^K \left[1 - \frac{\phi}{2} \left(\frac{I_t}{I_{t-1}} - e^g \right)^2 - \phi \left(\frac{I_t}{I_{t-1}} - e^g \right) \frac{I_t}{I_{t-1}} \right] \\ &\quad + \beta \frac{\Lambda_{t+1}}{\Lambda_t} Q_{t+1}^K \phi \left(\frac{I_{t+1}}{I_t} - e^g \right) \frac{I_{t+1}^2}{I_t^2} \end{aligned}$$

where the relative price of a unit of investment is naturally one, since consumption and investment goods are produced with the same technology. The entrepreneurial borrowing constraint holds with equality.

Production factors used by entrepreneurs are demanded according to the two factor demand conditions, which mandate a constant capital-to-labor ratio

$$\begin{aligned} r_t^K &= \alpha (L_{n,t})^{1-\alpha} K_{n,t}^{\alpha-1} \\ r_t^K &= \alpha \zeta P_{h,t} L_{h,t}{}^{(1-\alpha)\zeta} K_{h,t}^{\alpha\zeta-1} \mathcal{L}^{1-\zeta} \end{aligned}$$

where r_t^K is the shadow rental rate of capital used in each sector, which must be equal across sectors by the assumed homogeneity of capital. Similar conditions hold for labor demand

$$\begin{aligned} W_t &= (1-\alpha) L_{n,t}{}^{-\alpha} K_{n,t}^{\alpha} \\ W_t &= (1-\alpha) \zeta P_{h,t} L_{h,t}^{(1-\alpha)\zeta-1} K_{ht}^{\alpha\zeta} \mathcal{L}^{1-\zeta} \end{aligned}$$

where W_t is the wage paid in both sectors, which, again, must be equal due to perfect mobility of workers.[14] Transversality conditions and the production functions and budget constraints complete the description of the optimality conditions.

2.5 Solution and calibration

To determine the model's rational expectations equilibrium, and to describe its dynamics, all variables with a growth trend need to be transformed into stationary variables, and the parameters of the model need to be calibrated. We first describe the solution method and the role of imperfect information in the model, then discuss the stationary transformations, and finally introduce the calibration.

The standard methods of choice for solving rational expectations (or, dynamic stochastic general equilibrium, DSGE) models are based on the logic of Blanchard and Kahn

[14] Sector-specificity of labor is certainly an aspect of real world labor markets which warrants further investigation.

(1980), that rules out explosive paths for forward looking variables as a result of optimal behavior. Here we apply the methods of Sims (2002) as implemented in the Matlab program Dynare. The first-order solution of the model is a state-space system that describes the evolution of the model's variables as a function of their own lagged values and innovations to disturbances. The coefficients of the resulting transition matrix, and the impact effects of shocks are consistent with the optimal choices and rational expectations of all agents in the model.

In a conventional rational expectations model, there is full information by agents about all variables. In our case, as we assume imperfect information about some variables (the growth trends of g_t and $g_{z_h,t}$, as well as the level shock to technology), agents respond to their beliefs about these variables, rather then their true values. However, the optimization problem under these two scenarios does not change in nature: given the beliefs on the state of the economy, in particular, about the current state of the growth rate, g_t, agents make fully rational decisions, not anticipating that they will change their beliefs in the future. Thus we are applying the notion of anticipated utility, following Kreps and Porteus (1978).[15] We stress that the model does not depart from rational expectations per se, but only from the strong assumption of full information. We therefore denote households' expectations of the persistent component of the growth process based on their available information on date t as

$$g_{t|t} \equiv E_t g_t. \tag{5}$$

This expression accounts for the fact that households only observe the current level of technology Z_t, but cannot disentangle changes in $\ln Z_t$ from $\ln Z_{t-1}$ into one-off level shifts ω_t and persistent growth rate changes due to innovations in η_t, in the notation introduced above. They therefore form at each point in time a best estimate $g_{t|t}$ of the current level of trend growth. The same is true for $g_{z_h,t|t}$, the perceived values of the persistent component of the growth process in the housing sector.

Along a balanced growth path all variables must be growing at constant rates, and certain variables are to be constant in levels, such as the rental rate of capital. The stationary variables are denoted by lower case letters. Variables growing at rate g of Z_t are: $B_t = b_t Z_t$, $C_t = c_t Z_t$, $I_t = i_t Z_t$, $K_t = k_t Z_t$, $W_t = w_t Z_t$, and $Y_t = y_t Z_t$. The same is true for the components $C'_t, C''_t, C^e_t, K_{n,t}$, and $K_{h,t}$. In contrast, variables specific to the housing sector need the following transformations $q''_t Z_t^{1-\alpha\zeta}/Z_{h,t}^{(1-\alpha)\zeta} = Q''_t$, $q'_t Z_t^{1-\alpha\zeta}/Z_{h,t}^{(1-\alpha)\zeta} = Q'_t$, $p_{h,t} Z_t^{1-\alpha\zeta}/Z_{h,t}^{(1-\alpha)\zeta} = P_{h,t}$, $I_{h,t} = i_{h,t} (Z_t)^{\alpha\zeta} (Z_{h,t})^{(1-\alpha)\zeta}$, $H''_t = h''_t (Z_t)^{\alpha\zeta} (Z_{h,t})^{(1-\alpha)\zeta}$ and $H'_t = h'_t (Z_t)^{\alpha\zeta} (Z_{h,t})^{(1-\alpha)\zeta}$. Even without transformation the following variables are sta-

[15] See Cogley and Sargent (2008) for a recent discussion of anticipated utility.

tionary: $q_t = Q_t$, and the shadow rental rate of capital. Furthermore, the marginal utilities of wealth that we derive from the first-order conditions follow their own processes. For patient households, we have that $\Lambda'_t = \lambda_t (Z_t)^{\iota(1-\sigma)-1} \left[Z_t^{\alpha} Z_{h,t}^{1-\alpha}\right]^{\zeta(1-\iota)(1-\sigma)}$, with the same for impatient household.[16]

For the simulations of the model we define the structural parameter values as follows. Fundamental are the value for the different agents' discount factors and the borrowing constraints. Patient households, as the suppliers of funds to impatient households and entrepreneurs, have a discount factor $\beta' = 0.99$, which implies a steady state net real interest rate of $R - 1 = 1/\beta - 1 = 1.01$ percent, which implies an annual interest rate of 4.1 percent. This is also the steady-state interest rate for the rest of the world. Impatient households have a discount factor of $\beta'' = 0.95$, and entrepreneurs of $\beta = 0.98$. Thus the borrowing motive of the former is large. These motives for borrowing are constrained by the loan-to-value ratios required to obtain funds in financial markets. For entrepreneurs, we assume that 90 percent of the value of capital is collaterizable, hence $m = 0.9$, while for impatient households this factor is set to $m'' = 0.5$. A constant value for m'' seems a plausible approximation to the relatively unchanged aggregate loan-to-value ratio shown in Figure 1, nonwithstanding the redistributional aspects mentioned in the introduction.

The remaining preference parameters are equal across agents, and are largely standard in the literature. The intertemporal elasticity of substitution is $\sigma = 2$ and the inverse of the labor supply elasticity is $\psi = 1.5$. The disutility of labor is scaled by $\chi = 10$. The parameter ι in the utility function of households is set to 0.8, which roughly corresponds to the expenditure of non-housing in total consumption. In our calibration, we also assume that both household sectors are of size equal to the entrepreneurial sector, thus the relative sizes are set to $n' = n'' = 10$. The quantity of land is normalized to $\mathcal{L} = 1$.

The share of capital in the production function is set to $\alpha = 0.33$ and is equal across the housing and non-housing goods production functions. Capital and housing all depreciated at a common rate $\delta = 0.025$, roughly 10 percent annually. Also the adjustment cost parameters are assumed to be equal at $\phi = \phi_h = 5$, in the range of values found in estimated DSGE models, such as Smets and Wouters (2007).[17] As in Davis in Heathcote (2005) the land share in production $(1 - \zeta)$ is equal to 0.1. Finally, the persistencies of deviations of the growth rates g_t and $g_{z_h,t}$ of non-housing and housing technology, Z_t and $Z_{h,t}$, are equal at $\rho_g = 0.9$. Table 1 summarizes the calibration. In our analysis, we focus

[16] The equation systems with the transformed variables is given in the Appendix.

[17] The adjustment cost ϕ_h for housing investment may well be different, but has only minor impact on the simulations. It would require values in the range of $\phi_h = 50$, to obtain a slight amplification in the response of house prices to changes in growth expectations.

Parameter		*Value*
Discount factors		
patient households	β'	0.99
impatient households	β''	0.95
entrepreneurs	β	0.98
LTV ratio, households	m''	0.5
LTV ratio, entrepreneurs	m	0.9
Intertemporal elasticity	σ^{-1}	0.5
Labor supply elasticity	ν	1.5
Labor supply scale	χ	10
Share of non-housing	ι	0.8
Capital share in production	α	0.33
Depreciation rate	δ	0.025
Adjustment cost, capital	ϕ	5
Adjustment cost, housing	ϕ_h	5
Persistence of growth rate	ρ_g	0.9
Sectoral sizes	n', n''	10
Land share in production	$1 - \zeta$	0.1

Table 1: Parameter Calibration

on the evolution of productivity in the non-housing sector.

3 Model simulation

We use the calibrated model to explore the link between growth expectations and the evolution of U.S. house prices. The main part of the discussion focuses on the results of simulating the model by identifying published long-term growth expectations with beliefs on the persistent component of productivity growth, $g_{t|t}$.We compare the model-implied house prices with those in the data. Later, we use a structural approach to map the expectation formation of households, in order to better understand some of the model's mechanisms. Here, households apply the Kalman filter to infer the persistent component of productivity growth from observed productivity data.

3.1 Historical simulation

In this section, we leave the exact process by which agents form expectations on long-term growth $g_{t|t}$ unspecified and directly take a transformation of the measures published by Consensus Forecasts as an input to the model. The only other input into the model are historical productivity data. The surveys of Consensus Economics are a monthly survey of professional economists. Every six months this survey includes questions about participants' expectations of real GDP growth and other macroeconomic variables at horizons up to ten years. Starting in 1991, we use the real GDP growth expectations at the longest horizon (6 to 10 years ahead) for the U.S. Given the assumed process for the persistent component of productivity (3), and realizing that over that horizon most of growth should be driven by productivity, we can calculate the current belief $g_{t|t}$ from those future expectations. The time series of this statistic enters the simulation. We conducted the same simulation using the ten-year forecast of average labor productivity growth from the Survey of Professional Forecasters (SPF). These forecasts are published once a year around mid-February. Since both sources provide similar results, in our discussion below we concentrate on the historical simulation implied by Consensus Forecasts.

Figure 3 presents the result of our simulations. The solid line shows real house price data from FHFA as shown earlier in Figure 1, and the dashed line corresponds to the house price movements as measured by the weighted sum of Q_t' and Q_t'' in the model. For most of the sample, the two lines move closely. Notably, the relatively slow movement of actual house prices in the early 1990s is followed by a pronounced upturn in the late 90s. The model-implied house price starts accelerating only a little later. But from 2000 onward, the model features equally strong increases as in the data. This is in sharp contrast with a simulation that ignores the persistent nature of growth. In Davis and Heathcote's seminal paper, which laid the ground for the general equilibrium study of house prices, this turn is not captured, as the model focuses on variations about a linear, long-run trend.[18] Here, house prices are affected, because perceived changes in income growth rates have stronger present value implications than changes in levels.

Beginning 2005, the two lines diverge, as actual house prices experience yet another acceleration, while the model-implied price growth slows down. From the perspective of the simulated model, there is clearly a disconnect building up between house price growth warranted by beliefs about fundamentals, i.e., income growth expectations, and the U.S. housing market. As house prices kept increasing until about 2007, productivity growth expectations slowed further down and remained flat until the end of the sample. After 2007, house prices fall steeply and even undershoot the model's prediction. In fact, one might argue that the decline in house prices is excessive, and may revert back to a higher trend, at least as long as growth prospects remain as high as of the end of the sample.

[18] See Figure 2 in Davis and Heathcote (2005), p.777.

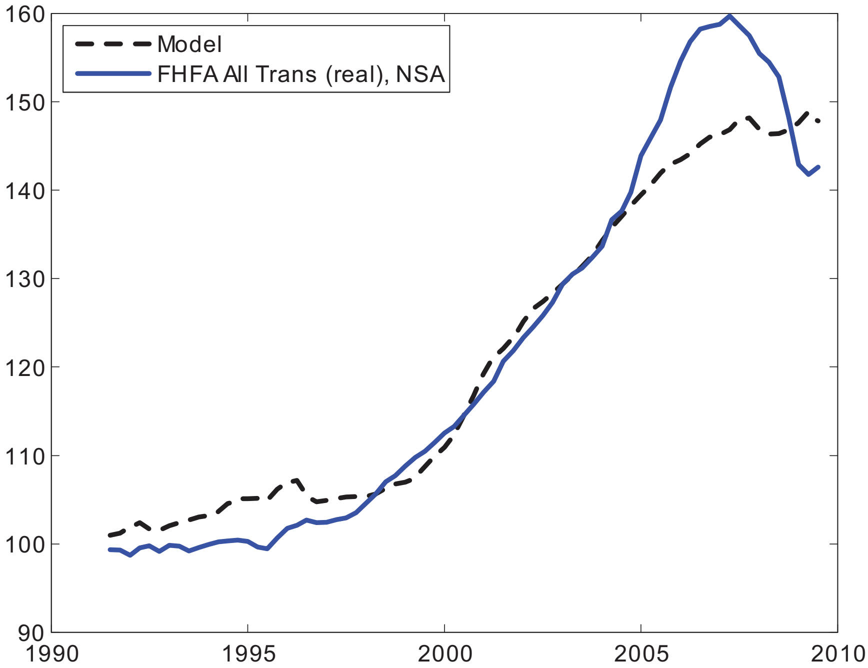

Figure 3: Actual and Simulated Real U.S. House Prices

The decoupling of actual house prices from the values implied by theory may be due to departures from rationality, or bubble-type phenomena, where agents extrapolate past house price movements into the future. This would delink current house prices from perceived aggregate fundamentals, i.e., productivity growth, and thus generate a housing boom. It seems possible that the resulting over-investment in housing after 2005 is also responsible for the sharp decline of house prices at the end of the decade, since it takes time to decumulate the inflated stock of housing. Before 2005, however, our model signals that changing trend growth expectations are an important force driving the value of housing.

An alternative, or even a complement, to irrational exuberance, may have been changes in the structure of housing finance, which have manifested themselves around 2005. Indeed, we have not modelled any changes in the loan-to-value ratio m'', motivated by the data shown in Figure 2. However, from 2006, the loan-to-value ratio rises. Also, the value of mortgage debt to disposable income has increased persistently, suggesting changes in financial instruments in the housing market.[19] Thus there may have been an increase in

[19] The model predicts an increase in total household debt to income of 41 percent between 1991 to 2007, where it peaks. This a similar magnitude as the change in mortgage debt since 1991 shown in Figure 2.

the amount of funds that impatient households may borrow against given collateral, raising demand for housing, and in turn push house prices further. Likewise, the collapse of the housing market would have been the consequence of the reversal in lending standards, triggered by the problems in the financial sector following the Lehman bankruptcy.[20] How an endogenous loan-to-value ratio would interact with the mechanism highlighted in this paper certainly warrants further research.

It might be argued that the link between income growth expectations and house prices reflects a reverse causality in that higher house price expectations trigger increases in borrowing which in turn affect aggregate spending and growth. Then changes in expectations would be endogenous to extraneous house price movements. This would leave open the question where house price movements come from. Furthermore, if this story were true, then growth expectations should also have increased after 2005, which we do not observe. Note that the simulations are robust to changes in most of the parameters. Steady-state levels depend on their values, but not much of their cyclical responses. The persistence of changes in the long-run growth rate, ρ_g, does affect the slope of the curve in the figure, but not the turning points in the time paths of house prices. The realistic value of 0.9 is sufficient to match the actual U.S. house price dynamics quite well. Therefore, we also keep the parameter values of Table 1 in the next section.

3.2 A structural interpretation of expectation formation

In order to highlight the workings of the model, we give one particular structural interpretation of changing growth expectations. In reality, forecasters use a host of information about future growth, but one important source is past productivity growth. To approximate the complex problem of forming expectations about future trend growth, we assume that agents use a Kalman filter to solve the signal-extraction problem of separating long-run from short-run fluctuations in productivity growth. The result of this filtering problem is an optimal estimate $g_{t|t}$ of the current rate of trend growth. This notion of learning is a departure from the full information typically assumed in rational expectations macroeconomics. However, this does not imply that we depart from rationality per se, but simply confront agents with a natural inference problem.

Given the linearity of our setup, the optimal estimate is obtained by the Kalman filter according to the recursion

$$g_{t|t} = (1 - \kappa)\rho_g g_{t-1|t-1} + \kappa \ln dz_t, \tag{6}$$

[20] See also Boz and Mendoza (2010), Figure 3.

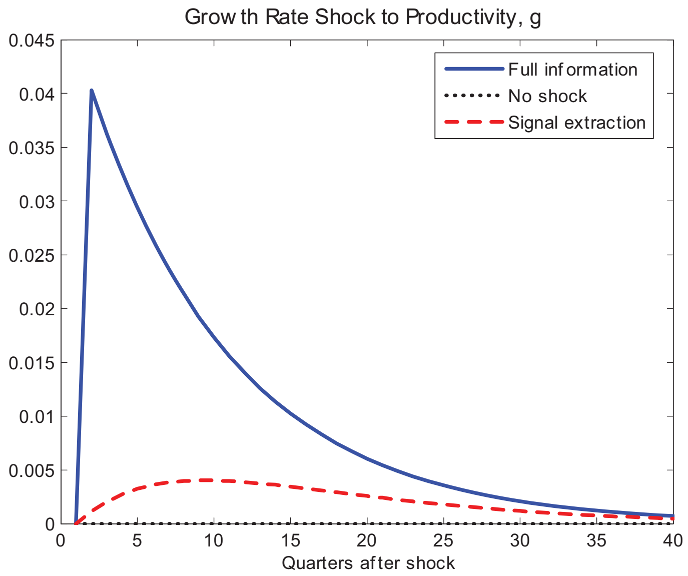

Figure 4: Actual and Perceived Persistent Component of Productivity Growth

where $dz_t = Z_t/Z_{t-1}$. The Kalman gain κ is given by

$$\kappa = \frac{\vartheta - (1-\rho_g^2) + \vartheta\sqrt{((1-\rho_g^2)/\vartheta)^2 + 1 + 2(1+\rho_g^2)/\vartheta}}{2 + \vartheta - (1-\rho_g^2) + \vartheta\sqrt{((1-\rho_g^2)/\vartheta)^2 + 1 + 2(1+\rho_g^2)/\vartheta}},$$

where the signal-to-noise ratio $\vartheta \equiv \sigma_\nu^2/\sigma_\omega^2$ measures the importance of innovations to trend growth relative to permanent one-off changes to the level of technology. All agents, domestic and foreign, are assumed to share the same signal extraction problem for the productivity process. As mentioned, we assume a persistence parameter $\rho_g = 0.9$, and a signal-to-noise ratio of $\vartheta = 0.0064$, which imply a Kalman gain of $\kappa = 0.0291$. This value for κ is in the range used in the literature.[21]

Figure 4 compares the actual evolution of the persistent component of trend growth with the current belief as obtained by the Kalman filter. One can see clearly how perceived productivity growth moves much slower in response to a shock. Instead, the filter assigns most of the movement in productivity to the transitory component, ω_t.

The interaction between productivity, house prices, borrowing constraints, and housing investment can be illustrated with the help of Figure 5. The first panel shows the level of productivity, as it results from transitory and permanent changes. The second panel shows clearly the difference in house prices between the hypothetical adjustment

[21] Edge, Laubach, and Williams (2007) and Gilchrist and Saito (2008) use the same approach.

under full information (the blue solid line), and the adjustment under the assumed signal extraction problem (the red dashed line). Under full information, households would know immediately that they can expect persistently higher house prices, as the value of housing increases with general productivity. However, under imperfect information, initial changes in trend growth are interpreted to be transitory, so that the adjustment takes place more slowly. There is in fact an overshooting of house prices in later periods, partly because housing is scarce relative to the demand arising from the pickup in perceived growth.

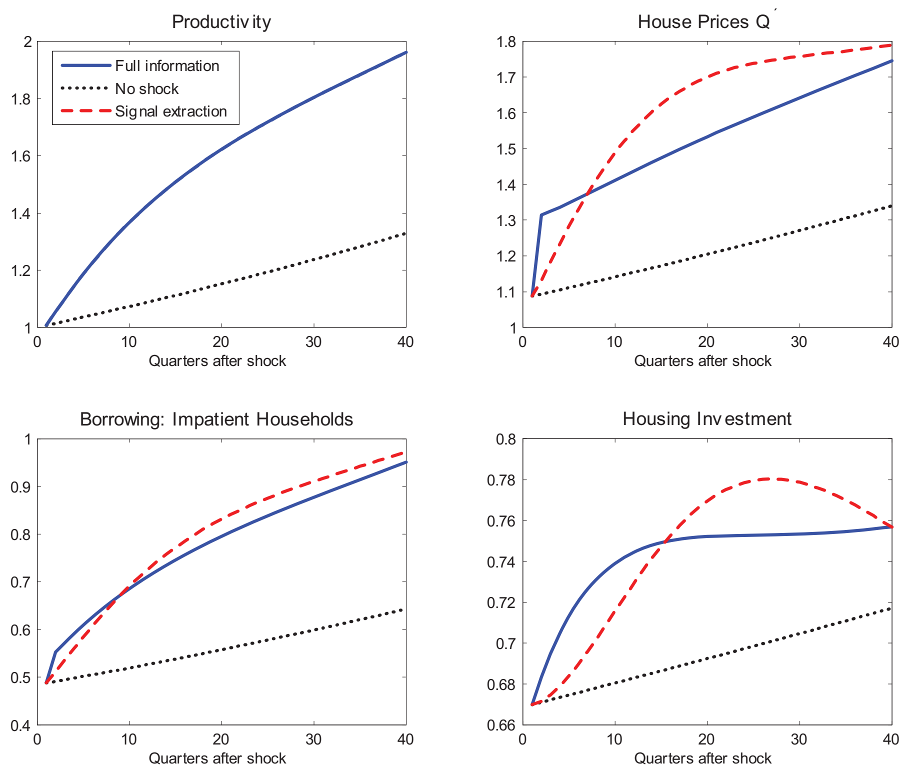

Figure 5: Impulse Responses of Productivity and Housing Variables (in levels

Correspondingly, borrowing by the credit-constrained, impatient, households also first lags behind the adjustment under full information. As perceived growth increases, and because the value of housing is rising, these households can increase their borrowing, as mandated by the borrowing constraint. The resulting higher investment by patient household in response to the higher value of housing is shown in the fourth panel.

4 Conclusions

In this paper we show that important aspects of the evolution of U.S. house prices in the last two decades are consistent with the predictions of a standard neoclassical growth model with three features: a housing market where some households are financially constrained, open international capital markets, and productivity whose growth *rates* exhibit persistent changes from their trend, rather than only variations of the *level* of productivity about a trend. The fact that current changes in trend growth rates are only imperfectly observable in economic data motivates our use of survey data on forecaster's concurrent perceptions of where income and productivity are heading in the future. In the model, more optimistic growth expectations lead to increases in the present value of housing services, that is, house prices.

Our simulations show that the economic structure of the model translates perceived trend growth rates into implied house prices dynamics that match the faster growth in actual house prices at the turn of the millennium. It also features slower house price growth by the end of 2009. However, the model can not match the additional acceleration of house prices that set in around 2005, and the sharp drop in prices since 2007/08. Instead, the model predicts merely a smooth slowdown in house price growth in that period, but not a significant decline. These results are robust to most of the particular parameter values, but depend crucially on the assumed small open economy structure of the model, which serves to proxy for the availability of external funds in the U.S., in particular in the first decade of the 2000s. Without this feature, interest rates would counterfactually rise after increases in productivity growth expectations, thus muting the dynamics of the housing market. To which extent the mechanism outlined here also helps understand similar housing market developments in other economies, for example in Spain or Ireland, we leave to future work.

The results have interesting implications for both policy and theory. In terms of economic theory, while the simulations explain most of house price changes as the outcome of rational behavior and unchanged financial parameters, the episode since 2005 poses new questions. The decoupling of actual house prices from the values implied by our model may be on the one hand due to departures from rationality, such as some form of exuberance setting in, or bubbles building up along the lines of Adam et al. (2011) or some yet to be specified mechanism. How this works in detail must be left to future research. On the other hand, particular developments in the financial sector may have taken over, which we left unmodelled. Here we have in mind changes in domestic or international financial markets, such as the accelerated use of mortgage-backed securities, which added to the inflow of funds available to borrowers particularly in the housing market. This may also have affected borrowing conditions in that mortgage originators increasingly lowered lending standards. In our model, this can be approximated by changes in the parameters governing the loan-to-value ratio in the borrowing constraint. In fact, this parameter is likely to be endogenous, as shown by John Geanakoplos (2011).

For the purpose of maintaining financial stability, the model may suggest a metric against which to judge house price, or more generally, asset price movements. Using data on house prices and growth expectations alone, one could follow whether changes in house prices in the model match the changes observed in the data. If they coincide, as around 2000, there may be no cause for concern, as subsequent house price changes continued to be smooth and in line with the model. If they diverge, as from 2005, there may be reason for a macro-prudential regulator or supervisor to be alerted. Irrespective of whether the model correctly predicts the level and trend slope of house prices on average, the slowdown in productivity growth should have led to a slowing down of house prices, in contrast to the actual evolution that followed. An important extension of the analysis would be to use measures of uncertainty of current trend growth estimates in order to be able to assess risks around current housing valuations. Whether this perspective turns out to be fruitful for the development of macro-prudential regulation remains to be seen, but we believe to have identified an interesting avenue for research.

Appendix

Stationary equilibrium conditions

In this Appendix, we present the model's equilibrium conditions in their stationary form. That is, all variables with a growth trend are being transformed into stationary variables, so that the model's rational expectations equilibrium dynamics can be determined. Along a balanced growth path all variables must be growing at constant rates, and certain variables must be constant in levels, such as the rental rate of capital.

In addition to the transformations presented in the text, define for convenience the relative growth rates $dz_t = Z_t/Z_{t-1}$ and $dz_{h,t} = Z_{h,t}/Z_{h,t-1}$. Defining now $dx_t \equiv \left(dz_t^{\alpha} dz_{h,t}^{1-\alpha}\right)^{\zeta}$, allows some simplifications. The marginal utility for patient households is

$$\lambda_t' = \left[(c_t')^{\iota} (h_t')^{(1-\iota)} \left(1 - \frac{\chi}{1+\psi} L_t'^{(1+\nu)}\right)\right]^{1-\sigma} \iota c_t'^{-1}$$

whose dynamics are governed over time by

$$1 = E_t \beta' \frac{\lambda_{t+1}'}{\lambda_t'} dz_{t+1}^{\iota(1-\sigma)-1} dx_{t+1}^{(1-\iota)(1-\sigma)} R_t$$

One can see how the weight ι and the growth rates affect the dynamics of the stationary variables. When $dz_t = dz_{h,t}$, then $dx_t = dz_t$ and $dz_{t+1}^{\iota(1-\sigma)-1} dx_{t+1}^{(1-\iota)(1-\sigma)} = dz_t^{-\sigma}$, as in a standard growth model. The same holds if housing is irrelevant with $\iota = 1$.

Investment in housing is guided by the dynamics of the real marginal value of a unit of installed housing accumulated by patient households:

$$q_t' = E_t \beta' \frac{\lambda_{t+1}'}{\lambda_t'} dz_{t+1}^{i(1-\sigma)} dx_{t+1}^{(1-\iota)(1-\sigma)-1} \left[\frac{1-\iota}{\iota} \frac{c_{t+1}'}{h_{t+1}'} + q_{t+1}'(1-\delta) \right]$$

where q_t' and the relative price of housing $p_{h,t}$ and investment $i_{h,t}$ are linked by

$$\begin{aligned} p_{h,t} &= q_t' \left[1 - \frac{\phi_h}{2} \left(\frac{i_{h,t}}{i_{h,t-1}} dx_t - e^{g_h} \right)^2 - \phi_h \left(\frac{i_{h,t}}{i_{h,t-1}} dx_t - e^{g_h} \right) \frac{i_{h,t}}{i_{h,t-1}} dx_t \right] \\ &\quad + E_t \beta' \frac{\lambda_{t+1}'}{\lambda_t'} dz_{t+1}^{i(1-\sigma)} dx_{t+1}^{(1-\iota)(1-\sigma)-1} q_{t+1}' \phi_h \left(\frac{i_{h,t+1}}{i_{h,t}} dx_{t+1} - e^{g_h} \right) \left(\frac{i_{h,t+1}}{i_{h,t}} \right)^2 dx_{t+1}^2. \end{aligned}$$

The sales of housing to impatient households must be consistent with

$$q_t^H = \beta' \frac{\lambda_{t+1}'}{\lambda_t'} dz_{t+1}^{i(1-\sigma)} dx_{t+1}^{(1-\iota)(1-\sigma)-1} (1-\delta) q_{t+1}^H + \frac{1-\iota}{\iota} \frac{c_t'}{h_t'}$$

The optimal choice of the labor imput is given by

$$w_t' = \frac{\chi}{\iota} c_t' \frac{L_t'^{(\nu)}}{1 - \frac{\chi}{1+\nu} L_t'^{(1+\nu)}}.$$

For impatient households, the Euler equation becomes

$$1 = E_t \beta'' \frac{\lambda_{t+1}''}{\lambda_t''} dz_{t+1}^{i(1-\sigma)-1} dx_{t+1}^{(1-\iota)(1-\sigma)} R_t + \eta_t''$$

where η_t'' is the real shadow value of the borrowing constraint, and correspondingly, the marginal utility of wealth is

$$\lambda_t'' = \left[(c_t'')^{\iota} (h_t'')^{(1-\iota)} \left(1 - \frac{\chi}{1+\nu} L_t''^{(1+\nu)} \right) \right]^{1-\sigma} \iota c_t''^{-1}$$

Optimal purchases of housing must obey, where the shadow value of the borrowing constraint guides the perceived benefits of buying or selling a marginal unit of housing

$$\begin{aligned} q_t^H &= E_t \beta'' \frac{\lambda_{t+1}''}{\lambda_t''} dz_{t+1}^{\iota(1-\sigma)} dx_{t+1}^{(1-\iota)(1-\sigma)-1} q_{t+1}^H (1-\delta) \\ &\quad + \eta_t'' m'' E_t \frac{q_{t+1}''}{R_t} \frac{dz_{t+1}}{dx_{t+1}} + \frac{1-\iota}{\iota} \frac{c_t''}{h_t''} \end{aligned}$$

In equilibrium, the stationary borrowing constraint holds with equality:

$$b_t'' = m'' E_t \left[\frac{q_{t+1}^H h_t''}{R_t} \frac{dz_{t+1}}{dx_{t+1}} \right]$$

For entrepreneurs, the marginal utility of wealth equals the marginal utility of consumption, $\lambda_t = (c_t^e)^{-\sigma}$, and the Euler equation is corrected for the value of the borrowing constraint

$$1 = \beta \frac{\lambda_{t+1}}{\lambda_t} dz_{t+1}^{-\sigma} R_t + \eta_t^e$$

and the marginal value of a unit of capital is given by the present value of all future marginal returns to using capital in production, r^K :

$$q_t = \beta \frac{\lambda_{t+1}}{\lambda_t} dz_{t+1}^{-\sigma} \left(q_{t+1}(1-\delta) + r_{t+1}^K \right) + m^e \eta_t^e E_t \left[\frac{q_{t+1}}{R_t} \right].$$

The relationship between the marginal value of an installed unit of capital and investment is governed by

$$\begin{aligned} 1 &= q_t \left[1 - \frac{\phi}{2} \left(\frac{i_t}{i_{t-1}} dz_t - e^g \right)^2 - \phi \left(\frac{i_t}{i_{t-1}} dz_t - e^g \right) \frac{i_t}{i_{t-1}} dz_t \right] \\ & \quad + E_t \beta \frac{\lambda_{t+1}}{\lambda_t} dz_{t+1}^{-\sigma} q_{t+1} \phi \left(\frac{i_{t+1}}{i_t} dz_{t+1} - e^g \right) \frac{i_{t+1}^2}{i_t^2} dz_{t+1}^2 \end{aligned}$$

The stationary borrowing constraint is

$$b_t^e = m E_t \left[\frac{q_{t+1} k_{t+1} dz_{t+1}}{R_t} \right]$$

The production factors used by entrepreneurs are demanded according to

$$\begin{aligned} r_t^K &= \alpha (L_{n,t})^{1-\alpha} k_{n,t}^{\alpha-1} \\ r_t^K &= \alpha \zeta p_{h,t} L_{h,t}{}^{(1-\alpha)\zeta} k_{h,t}^{\alpha\zeta-1} \end{aligned}$$

and

$$\begin{aligned} w_t &= (1-\alpha) L_{n,t}{}^{-\alpha} k_{n,t}^{\alpha} \\ w_t &= (1-\alpha) \zeta p_{h,t} L_{h,t}^{(1-\alpha)\zeta-1} k_{ht}^{\alpha\zeta} \end{aligned}$$

where w_t is the stationary wage paid in both sectors.

The stationary accumulation and market clearing conditions are as follows. Housing accumulation for patient households is given by

$$h_t = (1-\delta) h_{t-1} dx_t^{-1} + \frac{i_{h,t}}{n'} \left[1 - \frac{\phi_h}{2} \left(\frac{i_{h,t}}{i_{h,t-1}} dx_t - e^{g_h} \right)^2 \right]$$

where $h_{t-1}/dx_t = h'_t + n''/n'h''_t$, while capital follows

$$k_t = (1-\delta)k_{t-1}dz_t^{-1} + i_t\left[1 - \frac{\phi}{2}\left(\frac{i_t}{i_{t-1}}dz_t - e^g\right)^2\right].$$

Total income of the entrepreneur from the production of the construction and the normal good is given by

$$y_t = L_{n,t}{}^{1-\alpha}k_{n,t}^{\alpha} + p_{h,t}\left[(L_{h,t})^{1-\alpha}k_{h,t}^{\alpha}\right]^{\zeta}$$

Furthermore, $k_{t-1}/dz_t = k_{h,t} + k_{n,t}$, and $c_t \equiv c_t^e + n'c'_t + n''c''_t$. Finally, the model is closed by the respective budget constraints for the patient

$$w_t L'_t = c'_t + p_{h,t}\frac{i'_{h,t}}{n'} + R_{t-1}b'_{t-1}dz_t^{-1} - b'_t - q_t^H\frac{n''}{n'}h''_t + q_t^H\frac{n''}{n'}h''_{t-1}(1-\delta)/dx_t$$

and impatient households

$$w_t L''_t = c''_t + R_{t-1}b''_{t-1}dz_t^{-1} - b''_t + q_t^H h''_t - q_t^H h''_{t-1}(1-\delta)/dx_t$$

and finally for the entrepreneurs:

$$y_t + b_t^e = c_t^e + i_t + R_{t-1}b_{t-1}^e + w_t L_t.$$

Adding up these conditions, and using $b_t^e + n'b'_t + n''b''_t = b_t^* = NFA_t$ equals the net foreign asset position of households.

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