

Asset Pricing and Housing Supply in a Production Economy

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Abstract

The link between housing supply and house prices is studied in a general equilibrium model aimed at explaining several well-documented asset pricing anomalies. In a model generating an equity premium of 6.19% and a mean risk-free rate of 0.75%, we find that housing-supply restrictions have important quantitative implications. Firstly, introducing building restrictions enhances the ability of models with endogenous housing supply to explain asset pricing anomalies. Secondly, in an economy where habit formation generates a precautionary demand for housing services, we find that housing-supply restrictions lead to a substantial increase in the volatility of house prices.

*Email: ivan.jaccard@ecb.int . Correspondance: Monetary Policy Research Department, Kaiserstrasse 29, 60311 Frankfurt, Germany. This draft and a previous version entitled "Asset Pricing in Home Production Economies" has benefited from comments and suggestions from G. Lombardo, O. Tristani, E. Pasten, G. Korteweg, V. Chari, D. Cook, J. Heathcote, C. Leung, P.-O. Weill, L. Stracca, M. Piazzesi, S. Rebelo, two anonymous referees and seminar participants at the University of Mannheim, the University of Basel, the ECB, the Hong Kong Institute for Monetary Research, the WFA Meetings, the ESEM Meetings, the University of Munich. The views expressed in this paper do not necessarily reflect the views of the European Central Bank or any of the persons listed above and all potential errors and/or omissions are my own responsibility. Keywords: Risk-free Rate Puzzle, Habit Formation, Adjustment Costs, Housing Returns. JEL: E2, E3, G1

1 Introduction

A considerable amount of empirical evidence suggests that housing supply is constrained and that these constraints have a substantial impact on the dynamics of house prices [Glaeser and Gyourko (2003); Green, Malpezzi and Mayo (2005); Quigley and Raphael (2005)]. Glaeser, Gyourko and Saks (2005a, 2005b) for instance present evidence that, in the United States, rising house prices have been accompanied by reductions in residential developments and that regulation is constraining the supply of housing¹. Glaeser, Gyourko and Saiz (2008) study the impact of the elasticity of housing supply on the dynamics of house prices and show that, in general, areas with more inelastic supply experience larger increases in prices and much smaller increases in new construction.

Following these empirical findings, this study proposes to incorporate a housing sector into a dynamic general equilibrium model to study the asset pricing implications of housing supply. The framework is then used to firstly assess whether building restrictions could explain the high volatility of house prices observed in the data. This question is addressed in a model where residential investment and hours worked in the housing sector are endogenously determined. Additional model implications relevant to the housing sector can therefore be simultaneously tested.

Given that housing represents seventeen percent of total consumption expenditures, the second objective is to assess whether restrictions on housing supply could contribute to the resolution of asset pricing puzzles. By impairing households' ability to smooth their consumption of housing services over time, building restrictions could potentially affect agents' discount factors and may therefore contribute to explain asset pricing anomalies. The key question is to assess whether these effects could be quantitatively significant in a model with investment and endogenous labor supply.

To study these questions, a two-sector general equilibrium model where new homes are produced by a housing sector is developed. As in Davis and Heathcote (2005) [see also Iacoviello and Neri (2009)], the housing sector uses labor and residential capital to produce new homes and housing services are determined by the stock of housing which has been accumulated over the years. The non-housing sector is standard and produces a final output good

¹Ortalo-Magne and Prat (2007) study the determinants of housing supply regulation. See Di Pasquale (1999) for a review of the housing supply literature and Leung (2004) for a review of the macro-finance/housing literature.

which can be divided between non-housing consumption, business investment and residential investment.

Compared to Davis and Heathcote (2005), the first important difference is that building restrictions are introduced into the analysis. As far as the nature of these restrictions are concerned, we base our approach on the findings reported by Glaeser, Gyourko and Saks (2005) which emphasize the importance of regulation in making large-scale development more difficult. To keep the analysis tractable, this aspect is captured by introducing an adjustment cost on housing supply which makes large projects more expensive to implement than smaller ones.

As in a standard model, house prices are determined by an asset pricing formula equalizing the cost of buying a house today with the expected discounted payoff, where future payoffs depend on rents and on price appreciation. In the presence of building restrictions, the difference is that the textbook formula has to be adjusted to take into account the effects of supply constraints on the valuation. In a model with restrictions on housing supply, the equilibrium value of a house can therefore differ from the standard net present value formula.

Compared to Davis and Heathcote (2005), the second key difference is that the model is augmented with habit formation [Abel (1990), Constantinides (1990), Campbell and Cochrane (1999)]. To limit the number of free parameters, we assume that habits are formed over a mix of total consumption and leisure where total consumption is an aggregate of housing and non-housing consumption. This specification of habit formation only introduces one additional free parameter and enhances the ability of models with endogenous labor supply to explain asset pricing puzzles [Jaccard (2009)].

As far as the dynamics of house prices is concerned, we find that in a model able to potentially resolve several well-documented asset pricing anomalies, introducing building restrictions leads to a substantial increase in the volatility of house prices. As in Davis and Heathcote (2005), we also find that it would be very difficult to explain the high volatility of house prices observed in the United States in a model with endogenous housing supply but without building restrictions.

This result seems in line with the empirical facts reported by Glaeser, Gyourko and Saiz (2008) which emphasize the importance housing supply elasticities in explaining house price dynamics. As far as the volatility of house prices is concerned, our analysis also shows that while housing-supply regulation is essential, demand factors are an important part of the explana-

tion². In our economy, habit formation induces a precautionary demand for housing services which amplifies fluctuations in the demand for new homes. Without habit formation, the model augmented with building restrictions could not generate house price cycles of the amplitude that has been recently observed³.

These quantitative implications essentially rely on the model's ability to generate costly business cycle fluctuations [Alvarez and Jermann (2004), Barro (2006), Gourio (2009)] and empirically plausible risk premiums. Introducing a specification of habit formation which exacerbates the cost of uncertainty is particularly important. In such an environment, frictions affecting the potential for intertemporal smoothing have a large impact on risk premiums and on the dynamics of asset prices [Jermann (1998), Boldrin, Christiano and Fisher (2001)].

As in Piazzesi, Schneider and Tuzel (2007), we find that introducing housing services into the stochastic discount factors has key asset pricing implications. In our study however, the difference is that this effect depends crucially on the extent to which housing supply is constrained. Compared to the benchmark calibration, removing building restrictions would decrease the equity premium from more than six percent to about one percent.

This result illustrates that introducing housing services into the utility function could in principle generate a significant reduction in risk premiums. Given that housing services are derived from the housing stock, introducing a durable asset responding only gradually to shocks allows agents to better diversify consumption risk. In a model where housing supply is endogenously determined, introducing building restrictions therefore considerably enhances the model's ability to explain asset pricing anomalies.

The paper is structured as follows. Section 2 presents a set of asset pricing, business cycle and housing market facts for the United States. The theoretical environment is developed in section 3 and the asset pricing implications of the model are discussed in section 4. The calibration is presented in section 5 and the results are discussed in section 6. Section 7 concludes.

²Van Nieuwerburgh and Weill (2010) also attribute the increase in house price dispersion to a combination of supply and demand factors. According to their findings, while housing-supply regulation is important, the increase in wage dispersion is an essential part of the explanation.

³The model without habit formation would also be unable to generate a plausible equity premium.

2 Data Description

Empirical facts describing the volatility and the cyclical nature of the business cycle and the asset pricing variables under study are reported in Table 1 and have been computed using quarterly data. All the variables have been expressed in logs and the cyclical component has been extracted using a HP-filter.

Following the literature on the equity premium puzzle, Table 2 reports the mean and standard deviation of equity and housing returns. The financial statistics presented in Table 2 have been expressed in annualized percent.

Table 1: Volatility and Correlation

Total Output (HP-filter 1947-2009)			
	σ_{y_T}	$\rho(y_{Tt}, y_{Tt-1})$	$\rho(y_{Tt}, y_{Tt-4})$
y_T	1.68	0.81	0.19

Business Cycle Statistics (HP-filter 1947-2009)			
	σ_{x_i/y_T}	$\rho(x_{it}, y_{Tt})$	$\rho(x_{it}, x_{it-1})$
c_M	0.49	0.79	0.83
i_M	3.37	0.82	0.82
i_H	5.93	0.53	0.88
N_T	0.98	0.83	0.90
N_H	2.23	0.76	0.90
w_B	0.57	0.19	0.66
w_H	0.85	-0.16	0.64

Asset Prices (HP-filter 1987-2009)			
	σ_{x_i/y_T}	$\rho(x_{it}, y_{Tt})$	$\rho(x_{it}, x_{it-1})$
d_T	25.3	0.80	0.78
p_E	10.6	0.65	0.83
p_H	4.01	0.57	0.91
z_H	0.43	-0.03	0.78

In Table 1, the volatility of total output is denoted σ_{y_T} , and the relative standard deviation of variable x_i with respect to output is denoted $\sigma_{x_i}/\sigma_{y_T}$. The correlation of variable x_i with respect to output is denoted $\rho(x_{it}, y_{Tt})$

while $\rho(x_{it}, x_{it-1})$ denotes the first-order autocorrelation of variable x_i . Market consumption, which in the data corresponds to real consumption of services and of non-durables goods, is denoted c_M . Business investment, which corresponds to investment in equipment and software, is denoted i_M while residential investment is denoted i_H . Total hours worked are denoted N_T and correspond to a measure of total employment. Wages in the business sector are denoted w_B and correspond to a measure of real compensation per hour in the nonfarm business sector. Finally, employment and real wages in the housing sector are respectively denoted N_H and w_H , and correspond to a measure of total employment and earnings in the construction sector. Real wages in the construction sector have been deflated using CPI inflation. All eight series are taken from the online database of the St-Louis Fed.

House prices, equity prices and total earnings are denoted p_H, p_E and d_T . The Case-Shiller index is used as a proxy for house prices, and equity prices and earnings are taken from the online database of Robert Shiller. Compared to other house price indices, the advantage of the Case-Shiller index is that it includes transaction prices which are based on a wider range of mortgage contracts⁴. Residential rents are denoted, z_H , and are proxied using the housing component of the CPI index.

In Table 2, the equity premium and the housing risk premium are respectively denoted $E(r_M - r_f)$ and $E(r_H - r_f)$, where r_f is the real risk-free rate. The volatility of equity returns, of housing returns and of the risk-free rate are respectively denoted $\sigma(r_M)$, $\sigma(r_H)$ and $\sigma(r_f)$. Finally, the first order autocorrelation of equity returns, housing returns and of the risk-free rate is denoted $\rho(r_{Mt}, r_{Mt-1})$, $\rho(r_{Ht}, r_{Ht-1})$ and $\rho(r_{ft}, r_{ft-1})$. These financial statistics are taken from the study of Piazzesi, Schneider and Tuzel (2007).

Table 2: Financial Returns (Piazzesi, Schneider and Tuzel 2007)

Mean		
$E(r_M - r_f)$	$E(r_H - r_f)$	$E(r_f)$
6.19	1.77	0.75

⁴To be able to compare the volatility and standard deviation of house prices and equity prices, the sample is restricted to the period 1987-2009, since the Case-Shiller index is not available before 1987. Over the restricted sample 1987-2009, the standard deviation of equity price, σ_{p_E} , is 11.7 and the volatility of output, σ_{y_T} , is 1.1. Over the whole sample 1871-2009, the standard deviation of equity price, σ_{p_E} , is 12.1.

Standard deviation		
$\sigma(r_M)$	$\sigma(r_H)$	$\sigma(r_f)$
16.56	2.73	3.68
Autocorrelation		
$\rho(r_{Mt}, r_{Mt-1})$	$\rho(r_{Ht}, r_{Ht-1})$	$\rho(r_{ft}, r_{ft-1})$
-0.06	0.48	0.73

3 The Environment

There are two production sectors in this economy. Output in the market sector is produced using labor and business capital. The housing sector produces new homes using residential capital and labor. The representative agent divides his time between leisure activities, hours worked in the market sector, and hours worked in the housing sector. To simplify the exposition, we firstly present the social planner's problem.

The specification of preferences and technology is compatible with balanced growth and small letters are used to denote detrended variables. The deterministic growth rate at which the economy is growing along the balanced growth path is denoted, γ .

Preferences

In this economy, utility is derived from consuming a market consumption good, c_{Mt} , from enjoying leisure, which we denote L_t , and from the housing stock which has been accumulated over the years, h_t . To keep the analysis tractable, we assume that habits are formed over the mix of consumption and leisure [Jaccard (2009)]. This specification permits to avoid introducing a reference level for all the different components entering the utility function. Following Constantinides (1990), an internal specification of habit formation is adopted and lifetime utility is given by:

$$U = E_0 \left\{ \sum_{t=0}^{\infty} \beta^{*t} \frac{1}{1-\sigma} [c_{Mt}^{\kappa} h_t^{1-\kappa} v(L_t) - x_t]^{1-\sigma} \right\}$$

where x_t is the habit stock or reference level. Net utility is given by the difference between the composite good, $c_{Mt}^{\kappa} h_t^{1-\kappa} v(L_t)$, and the reference level, x_t . The modified discount factor and the deterministic coefficient of relative risk aversion are respectively denoted⁵ β^* and σ .

⁵where $\beta^* = \tilde{\beta}\gamma^{1-\sigma}$

As in Constantinides (1990), the evolution of the habit stock is governed by a law of motion which allows for memory effects:

$$\gamma x_{t+1} = mx_t + (1 - m)c_{Mt}^\kappa h_t^{1-\kappa} v(L_t)$$

where m captures the rate at which the habit stock depreciates. To restrict the number of degrees of freedom, we assume that the parameter measuring the impact of $c_{Mt}^\kappa h_t^{1-\kappa} v(L_t)$ on the habit stock is given by $1 - m$. Compared to a macro-housing model [Davis and Heathcote (2005)], this specification of habit formation therefore only adds one free parameter.

As far as the allocation of time is concerned, households decide how to divide their time endowment between leisure activities, hours worked in the business sector and hours worked in the housing sector. Normalizing the total time endowment to 1, we have that:

$$N_{Tt} + L_t = 1$$

where:

$$N_{Tt} = N_{Mt} + N_{Ht}$$

and where N_{Tt} , N_{Mt} and N_{Ht} respectively denote the total number of hours worked, hours worked in the market sector, and hours worked in the housing sector.

Resource Constraint and Final Output Good

Market output, y_{Mt} , can be divided between market consumption, c_{Mt} , business or non-residential investment, i_{Mt} , and residential investment, i_{Ht} :

$$y_{Mt} = c_{Mt} + i_{Mt} + i_{Ht}$$

The production function of the final market output good has the standard Cobb-Douglas characterization:

$$y_{Mt} = A_{Mt} k_{Mt}^\alpha N_{Mt}^{1-\alpha}$$

where A_{Mt} , k_{Mt} and N_{Mt} respectively denote total factor productivity in the market sector, business capital, and hours worked in the market sector.

Housing Supply

As in Davis and Heathcote (2005), the stock of effective housing, h_t , depends on the amount of new homes produced, y_{Ht} . The production function of new homes has the standard Cobb-Douglas characterization:

$$y_{Ht} = A_{Ht} k_{Ht}^\varphi N_{Ht}^{1-\varphi}$$

where N_{Ht} , k_{Ht} and A_{Ht} respectively denote hours worked in the housing sector, the stock of residential capital or structures, and total factor productivity in the housing sector. The addition of a sector producing new homes introduces a distinction between residential capital, k_{Ht} , and the stock of effective housing, h_t . While residential structures need to be combined with hours worked in the housing sector to produce new homes, residential structures do not directly enter the utility function of the representative agent.

Restrictions on housing supply are captured by the introduction of an adjustment cost and the law of motion characterizing the evolution of the housing stock is given by:

$$(1 - \delta_H)h_t + \phi\left(\frac{y_{Ht}}{h_t}\right)h_t = \gamma h_{t+1} \quad (1)$$

where δ_H is the depreciation rate of the housing stock. To keep the analysis as general as possible, the type of adjustment costs used by Jermann (1998) in the context of asset pricing models is adopted⁶. This specification also limits the number of free parameters by making the steady state with and without adjustment costs similar⁷. The introduction of housing supply restrictions can be summarized by one single elasticity parameter, ϵ_H , capturing the curvature of the adjustment cost function⁸:

$$\epsilon_H = \frac{\phi''\left(\frac{y_H}{h}\right)\frac{y_H}{h}}{\phi'\left(\frac{y_H}{h}\right)}$$

Our specification which abstracts from land would be consistent with the facts reported by Glaeser, Gyourko and Saks (2005a, 2005b) suggesting that these constraints are not caused by a declining availability of land but are

⁶Lucas and Prescott (1971), Hayashi (1982) and Baxter and Crucini (1993) also study models with similar types of adjustment costs.

⁷Near the steady state, we have that: $\phi\left(\frac{y_H}{h}\right) > 0$, $\phi'\left(\frac{y_H}{h}\right) > 0$ and $\phi''\left(\frac{y_H}{h}\right) < 0$.

⁸The case $1/\epsilon_H = \infty$ corresponds to a model without adjustment costs while the case $1/\epsilon_H = 0$ corresponds to a specification with infinite adjustment costs.

rather the result of housing-supply regulation. The above specification which increases the cost of large projects, as measured by changes in y_{Ht}/h_t , aims at capturing that housing-supply regulation makes large-scale developments more costly to implement

Capital Accumulation

As shown by Jermann (1998), production economy models with investment and habit formation cannot generate plausible asset pricing predictions without capital adjustment costs. While capital adjustment costs also play a key role in our study, as we will show in the next section, a model with adjustment costs but without housing supply restrictions would fail on several key dimensions.

To keep the analysis as simple as possible, we assume that the accumulation of business and residential capital is subject to the same type of adjustment costs as housing and that the accumulation of business capital, k_{Ht} , and residential capital, k_{Mt} , is governed by the following laws of motion:

$$(1 - \delta_{k_H})k_{Ht} + \phi\left(\frac{i_{Ht}}{k_{Ht}}\right)k_{Ht} = \gamma k_{Ht+1} \quad (2)$$

$$(1 - \delta_{k_M})k_{Mt} + \phi\left(\frac{i_{Mt}}{k_{Mt}}\right)k_{Mt} = \gamma k_{Mt+1} \quad (3)$$

where:

$$\epsilon_{k_H} = \frac{\phi''\left(\frac{i_H}{k_H}\right)\frac{i_H}{k_H}}{\phi'\left(\frac{i_H}{k_H}\right)}, \quad \epsilon_{k_M} = \frac{\phi''\left(\frac{i_M}{k_M}\right)\frac{i_M}{k_M}}{\phi'\left(\frac{i_M}{k_M}\right)}$$

and where the depreciation rates of residential capital and business capital are denoted δ_{k_M} and δ_{k_H} . At this stage, to avoid introducing any additional free parameters, we assume that the degree of capital and housing adjustment costs are pinned down by a single elasticity parameter, ϵ , where:

$$\epsilon = \epsilon_{k_H} = \epsilon_{k_M} = \epsilon_H$$

Relaxing this assumption would obviously help the model to match a larger number of facts but would come at the cost of introducing several additional parameters for which a priori knowledge is weak. At this stage, the parameter ϵ should therefore be seen as a supply parameter to be estimated and which affects the accumulation of physical assets.

Our mechanism should be robust to a more realistic specification of capital adjustment costs. As shown by Tuzel (2009) for instance, asymmetric adjustment costs contribute to increase the risk premium required to hold firms with high real estate holdings. Given the slow depreciation rate of residential capital, assuming costly reversibility would further reduce the potential for intertemporal smoothing and should therefore reinforce the mechanism under study.

4 Asset Pricing Implications

Using the equivalence between the centralized and the competitive equilibrium allows us to firstly derive the standard asset pricing formula characterizing the dynamics of equity prices⁹. Equity prices, p_{Et} , can be derived from the first-order conditions of the households and expressed as the infinite discounted sum of future dividends, or equivalently, as an intertemporal arbitrage equation where the cost of buying the asset today and tomorrow's expected future gains have to be equalized:

$$p_{Et} = \beta^* E_t \frac{\lambda_{t+1}}{\lambda_t} [d_{t+1} + p_{Et+1}] \quad (4)$$

Equity returns are given by the standard definition:

$$r_{Mt,t+1} = \frac{p_{Et+1} + d_{t+1}}{p_{Et}}$$

This asset pricing formula corresponds to a competitive equilibrium where output and new homes are produced by an aggregate corporate sector. The representative firm owns the stocks of housing which is then rented to the representative households at the rental rate z_{Ht} .

The firm needs labor to produce new homes, y_{Ht} , and the final output good, y_{Mt} . Wages paid to workers in the market and in the housing sectors are respectively denoted w_{Mt} and w_{Ht} . The firm owns the stock of business and residential capital and investment is financed via retained earnings. Production, rental income, labor costs and investment determine the component of dividends related to operating profits and which is entirely financed via retained earnings.

⁹The first-order conditions are derived in the appendix.

In practice, borrowing is an important source of financing and the majority of firms finance part of their activity through debt. To capture the impact of leverage on the dynamics of dividends, borrowing is introduced by assuming that firms can issue a corporate bond, b_t . Since in this environment firms cannot default, funds from the representative household can be obtained at the risk-free rate, r_{ft} .

Deriving a model of optimal capital structure would be beyond the scope of this paper. To keep the analysis simple, we follow Jermann (1998) and Abel (1999), and assume that the amount of debt, b_t , is proportional to an exogenously specified fraction of the firm's total assets¹⁰. In our case, the difference is that total assets are not only composed of business capital but also depends on residential capital and on the housing stock.

Managers discount the flow of future dividends, d_t , using the discount factor of the representative agent and solve the following maximization problem:

$$Max E_0 \sum_{t=0}^{\infty} \beta^{*t} \frac{\lambda_t}{\lambda_0} d_t$$

such that:

$$d_t = y_{Mt} + z_{Ht}h_t - w_{Mt}N_{Mt} - w_{Ht}N_{Ht} - i_{KHt} - i_{Mt} + \gamma b_{t+1} - (1 + r_{ft})b_t$$

and subject to the accumulation equations (1), (2) and (3).

House Prices

House prices can be characterized by an intertemporal arbitrage equation linking prices to fundamentals:

$$p_{Ht} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} [(1 - \delta_H + \omega_{t+1}) p_{Ht+1} + z_{Ht+1}]$$

where:

$$\omega_{t+1} = \phi \left(\frac{y_{Ht+1}}{h_{t+1}} \right) - \phi' \left(\frac{y_{Ht+1}}{h_{t+1}} \right) \frac{y_{Ht+1}}{h_{t+1}}$$

where $\beta = \tilde{\beta}\gamma^{-\sigma}$. Compared to equity prices, the fact that the housing stock depreciates and that the accumulation of housing is subject to adjustment costs creates a wedge which shows up in the asset pricing formula.

¹⁰Given that firms borrow from the representative agents who is the owner of the firm, leverage has no impact on the allocation of quantities and only affects financial returns in the competitive equilibrium.

Adjustment costs and physical depreciation affect the dynamics of house prices through the capital gain component of the valuation. The term ω_{t+1} captures the impact of the adjustment costs which has to be paid for each additional housing unit built. Compared to a financial asset, the capital gain component also has to be adjusted for the fact that the housing stock depreciates at rate δ_H .

The payoff from increasing the stock of housing is determined by the rental rate, z_{Ht} . In the decentralized equilibrium, the rental rate of housing is given by the following ratio of marginal utilities:

$$z_{Ht} = \frac{U_h(c_{Mt}, h_t, L_t)}{U_{c_M}(c_{Mt}, h_t, L_t)}$$

where U_{c_M} and U_h respectively denote the marginal utility of market consumption and of the housing stock. With the specification of preferences that has been adopted, this expression reduces to:

$$z_{Ht} = \frac{(1 - \kappa) c_{Mt}}{\kappa h_t}$$

Most of the empirical literature studying the determinants of housing returns usually abstracts from the potential impact of adjustment costs on the return of housing investments [see Piazzesi, Schneider and Tuzel (2007); Flavin and Yamashita (2002) for instance]. To ensure consistency between the model implications and the empirical facts, we adopt a standard definition and define housing returns, $r_{H,t+1}$, as:

$$r_{H,t+1} = \frac{(1 - \delta_H)p_{Ht+1} + z_{Ht+1}}{p_{Ht}}$$

5 Parameter Selection

The parameter selection is carried out in two steps. A first set of parameters is chosen based on National Income Account data, following the standard in the business cycle literature. A second set of parameters, for which a priori knowledge is weak, is chosen to maximize the model's ability to replicate a set of asset pricing moments of interest, namely the equity premium and the risk-free rate.

Preference Parameters

With internal habit formation, the coefficient of relative risk aversion is independent of the habit parameter, m , and is exactly equal to the curvature parameter σ [see Jaccard (2009)]. To ensure that the conclusion of this study do not rely on an implausible curvature coefficient, we propose to pick a conservative value and to set σ to 3, as suggested by Kocherlakota (1996).

To maximize the model's ability to explain the low mean risk-free rate, the subjective discount factor β^* is set to 0.99, which is a standard value used in the literature [see Jermann (1998) for instance]. Setting β^* to 0.99 implies an annualized deterministic risk-free rate of about 3.5%.

Market Sector and Growth Rate

The quarterly trend growth rate γ is set to 1.005 and the constant capital share in the Cobb-Douglas production function, α , is 0.36. These are standard values used in the literature. Following Davis and Heathcote (2005), the depreciation rate of business capital, δ_M , is set to 0.0136.

Housing Sector

Following Davis and Heathcote (2005), the depreciation rate of residential structure, δ_{k_H} , and the depreciation rate of the housing stock, δ_H , are set to 0.0039 and 0.0035. Given that our production function of new homes depends on labor and residential capital and that land is excluded from the analysis, the estimated values reported by Jin and Zeng (2004) are used, and the residential capital share φ is set to 0.13.

Housing and Non-housing Consumption Share

With Cobb-Douglas, the expenditure share of non-housing consumption is given by the utility weight, κ :

$$\frac{c_{Mt}}{z_{Ht}h_t + c_{Mt}} = \kappa$$

The empirical evidence presented in Piazzesi, Schneider and Tuzel (2007) can therefore be used to calibrate κ using data on the expenditure share of housing and non-housing consumption. Following their empirical findings, we set κ to 0.826, which implies that housing consumption represents seventeen percent of total consumption.

Hours Worked

Evidence from the 2008 time of use survey is firstly used to calibrate the steady state value of N_T . In 2008, households spent on average 3.75 hours

on work related activities. Assuming that the available time for leisure and working activities is 16 hours per day, this implies a steady state value for N_T of about 0.23.

Next, a steady state restriction derived from the structure of the model is exploited to calibrate N_H and N_M . In the steady state, the first-order conditions with respect to N_{Ht} , N_{Mt} and c_{Mt} can be used to derive the following condition:

$$\frac{N_M}{N_H} = \frac{y_M (1 - \alpha) [1 - \beta(1 - \delta_H)]}{c_M (1 - \varphi) \beta} \frac{\kappa}{(1 - \kappa)} \frac{h}{y_H}$$

Given the above value for N_T , the fact that the ratio N_M/N_H is endogenously determined allows us to pin down the steady state time allocation. Given values for c_M/y_M and h/y_H which are endogenously determined in the deterministic steady state, we find that: $N_H = 0.0225$ and $N_M = 0.2094$. The model therefore predicts a steady state share of hours worked in the housing sector, N_H/N_T , of about 10%.

To assess the relevance of this model implication, we construct an empirical counterpart using data on total employment and on employment in the construction sector¹¹. Using this empirical measure of time allocation as a proxy for N_H/N_T , we find that hours worked in the construction sector represents on average 6.1% of total employment.

Labor Supply

The introduction of endogenous labor supply involves the calibration of two additional parameters controlling the curvature of $v(L)$. The above labor market restrictions which implies that in the steady state $N_T = 0.23$, pins down $v'(L)/v(L)$. The second elasticity parameter, $v''(L)/v'(L)$, determines the elasticity of labor supply. To our knowledge empirical evidence regarding the elasticity of labor supply in the construction sector are not available. Given this lack of a priori knowledge, we choose a value for $v''(L)/v'(L)$ which implies an elasticity of labor supply in the total number of hours worked, N_T , of about 1. Values for the Frisch elasticity of labor supply that are used in the literature usually range from 1 to 4 [see King and Rebelo (1999); Uhlig (2007)].

Productivity Shock

Following the real business cycle literature, we assume that technology shocks are the only source of business cycle fluctuations. To avoid introducing

¹¹Data on hours worked in the construction sector are not available.

any exogenous source of asymmetry, we further assume that both sectors are equally affected by technology shocks and that $A_{Mt} = A_{Ht} = A_t$. Total factor productivity, A_t , has the usual autoregressive characterization:

$$A_t = \rho A_{t-1} + \varepsilon_t$$

Compared to Davis and Heathcote (2005) and Greenwood and Hercowitz (1991), the number of degrees of freedom is therefore reduced by considering an economy where business fluctuations are entirely driven by one single exogenous shock. Following King and Rebelo (1999) we set the innovation standard deviation σ_ε to 0.0072, and the persistence parameter ρ to 0.979.

As shown by Chari, Kehoe and McGrattan (2007) fluctuations caused by technology shocks can be reinterpreted as variations in the efficiency wedge. The equivalence results presented in their study allow us to interpret technology shocks in a broader sense. Variations in the efficiency wedge can reflect underlying frictions affecting the allocation of factor inputs [see Restuccia and Rogerson (2008) for instance]. As they show, variations in the efficiency wedge can also capture financial frictions leading to an inefficient allocation of input across firms.

Leverage

Leverage is introduced as in Jermann (1998). The leverage ratio is calibrated using available empirical evidence on the debt to equity ratio for non-farm nonfinancial corporate firms in the United States¹². Over the period 1947-2009, the average debt to equity ratio is 0.564. The level of borrowing b_t is pinned down by the following condition:

$$\tau = \frac{b_t}{k_{Tt}}$$

where τ is the leverage ratio, set to 0.564, and where the total capital stock, k_{Tt} , is given by sum of the three assets held by the firm, namely business capital, residential capital, and the housing stock.

Adjustment Costs, Habit Formation, and Subjective Discount Factor

Given that to limit the number of free parameters we have assumed that the degree of adjustment costs is similar across sectors, the 2 remaining

¹²See flow of funds accounts, B.102 Balance Sheet of Nonfarm Nonfinancial Corporate Business, line 105.

parameters to select are the supply parameter, ϵ , and the habit parameter, m . This second set of parameters is picked to maximize the model's ability to match the equity premium and the mean risk-free rate. The parameter search has been restricted to the following range of values:

$$m = [0 : 1], \quad \epsilon = [0.0 : 6.25]$$

As regards the adjustment cost parameter, the model without adjustment costs correspond to the case $\epsilon = 0$ and values for ϵ larger than 6.25 are ignored since they are usually considered implausible [Jermann (1998)]. In the case $m = 1$, the model reduces to the model without habit formation.

6 Results and Discussion

The model's ability to match the equity premium and the mean risk-free rate is maximized at the following values for ϵ and m :

$$m = 0.875, \quad \epsilon = 3.24$$

Table 3: Output and Business Cycle Statistics¹³

Total Output (HP-filter)						
	σ_{y_T}		$\rho(y_{Tt}, y_{Tt-1})$		$\rho(y_{Tt}, y_{Tt-4})$	
	Data	Model	Data	Model	Data	Model
y_T	1.68	1.27	0.81	0.72	0.19	0.12

Business Cycle Statistics (HP-filter)						
	σ_{x_i/y_T}		$\rho(x_{it}, y_{Tt})$		$\rho(x_{it}, x_{it-1})$	
	Data	Model	Data	Model	Data	Model
c_M	0.49	0.54	0.79	0.99	0.83	0.72
i_M	3.37	2.17	0.82	0.99	0.82	0.72
i_H	5.93	2.74	0.53	0.99	0.88	0.72
N_T	0.98	0.48	0.83	0.99	0.90	0.72
N_H	2.23	1.75	0.76	0.99	0.89	0.72
w_B	0.57	0.61	0.19	0.99	0.66	0.72
w_H	0.85	0.61	-0.16	0.99	0.65	0.72

¹³The results from the model reported in Table 3 have been computed using theoretical HP-filtered moments.

Asset Prices (HP-filter)						
	σ_{x_i/y_T}		$\rho(x_{it}, y_{Tt})$		$\rho(x_{it}, x_{it-1})$	
	Data	Model	Data	Model	Data	Model
d	25.3	21.7	0.80	0.99	0.78	0.72
p_E	10.6	13.6	0.65	0.99	0.83	0.72
p_H	4.01	7.45	0.57	0.99	0.91	0.72
z_H	0.43	0.55	-0.03	0.99	0.78	0.72

Table 4: Financial Returns¹⁴

Mean in annualized (% p.a.)					
$E(r_M - r_f)$		$E(r_f)$		$E(r_H - r_f)$	
Data	Model	Data	Model	Data	Model
6.19	6.19	0.75	0.75	1.77	3.32

Standard deviation (% p.a.)					
$\sigma(r_M)$		$\sigma(r_H)$		$\sigma(r_f)$	
Data	Model	Data	Model	Data	Model
16.56	26.9	2.73	14.7	3.68	4.3

Autocorrelation					
$\rho(r_{Mt}, r_{Mt-1})$		$\sigma(r_{Ht}, r_{Ht-1})$		$\sigma(r_{ft}, r_{ft-1})$	
Data	Model	Data	Model	Data	Model
-0.06	-0.01	0.48	-0.01	0.73	0.98

The model's ability to explain the equity premium and the mean risk-free rate in an environment where labor supply is endogenously determined essentially relies on the assumption that habits are formed over a mix of consumption and leisure [Jaccard (2009)]. Introducing habit formation in the mix of consumption and leisure gives rise to a particular smoothing motive which decreases the volatility of $c_{Mt}^\kappa h_t^{1-\kappa} v(L_t)$ and increases the volatility of marginal utility. Larger fluctuations in marginal utility allows the model to generate the necessary increase in the stochastic discount factor volatility which is needed to explain asset pricing facts.

The key is that this specification of habit formation permits to simultaneously reduce the wealth elasticity of labor supply [Greenwood, Hercowitz

¹⁴The results from the model reported in Table 4 have been computed using theoretical moments. The results are expressed in annualized percent.

and Huffman (1988)]. Given that large movements in marginal utility are needed to explain asset pricing facts, decreasing the sensitivity of labor supply to movements in marginal utility is essential. Without this reduction in the wealth effect, agents would use labor supply to decrease the volatility of hours worked. This reduction in the volatility of hours would then generate a counterfactual reduction in the volatility of output and weaken the model's propagation mechanism. Finally, without a reduction in the wealth effect, the fact that agent could use the labor market to better insure themselves against shocks would compromise the model's ability to explain the equity premium [Boldrin, Christiano and Fisher (2001); Uhlig (2007a,b); Guvenen (2009)].

6.1 Residential Investment

As shown in Table 3, the benchmark model cannot explain the high volatility of residential investment, which is about twice as volatile as business investment in the data. To assess the extent to which our results depend on this counterfactual implication, we now ask whether it would still be possible to generate a plausible equity premium in a model able to match the relative standard deviation of residential investment, $\sigma_{i_H}/\sigma_{y_T}$. To keep the analysis simple, this experiment is performed by only varying the residential capital adjustment costs parameter, ϵ_{k_H} . The business investment and the housing-supply adjustment costs parameters, ϵ_{k_H} and ϵ_H are kept at 3.24 and are not adjusted to match the equity premium.

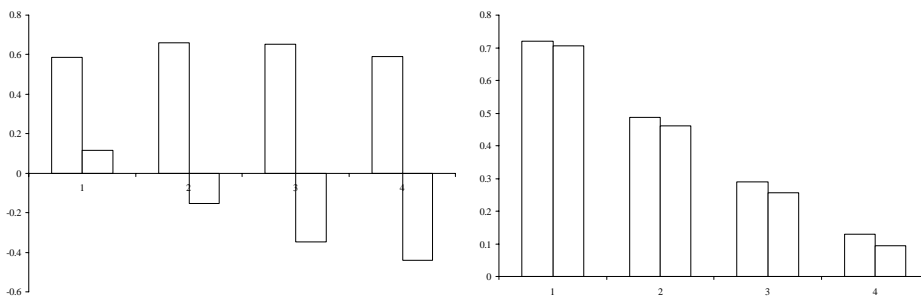
Lowering the residential adjustment costs parameter, ϵ_{k_H} , reduces the cost of adjusting residential investment and therefore increases $\sigma_{i_H}/\sigma_{y_T}$. Lowering the cost of adjusting residential capital also facilitates intertemporal smoothing and generates a decline in the compensation for risk required to hold risky assets [Jermann (1998)]. Table 5 below shows that decreasing ϵ_{k_H} from 3.24 to 1.3 would allow the model to match $\sigma_{i_H}/\sigma_{y_T}$ without compromising its ability to generate a high equity premium, since this improvement would come at the cost of lowering the equity premium from 6.19% to 6.0%. The mean risk-free rate, $E(r_f)$, and the standard deviation of business investment, $\sigma_{i_M}/\sigma_{y_T}$, would be little affected.

Table 5: Residential Investment

	Data	$\epsilon_{k_H} = 1.3$	$\epsilon_{k_H} = 3.24$
$\sigma_{i_H}/\sigma_{y_T}$	5.92	5.95	2.74
$\sigma_{i_M}/\sigma_{y_T}$	3.37	2.12	2.17
$E(r_M - r_f)$	6.19	6.0	6.19
$E(r_f)$	0.75	0.78	0.75

The assumption that both types of investment are subject to the same adjustment costs is however rejected by the facts. Figure 1 compares the lead-lag correlations of business and residential investment predicted by the model (right panel), in the case $\epsilon_{k_H} = 1.3$ discussed above, with the empirical facts (left panel).

Figure 1: Residential and Business Investment¹⁵



As documented by Fisher (2007), and as shown by the left panel, residential investment leads business investment over the cycle: $corr(i_M, i_{Ht-k}) > corr(i_{Mt-k}, i_H)$. The right panel of figure 1 illustrates that while the model can generate a small difference which goes in the right direction, it is not possible to quantitatively account for this robust empirical regularity. When it comes to alternative specifications of adjustment costs, the findings presented by Gomme, Kydland and Rupert (2001) suggest that introducing time-to-build into the analysis would be a natural direction for future research.

¹⁵Figure 1: The left panel shows the cross correlogram between residential and business investment. The series have been expressed in logs and HP-filtered. For each lag considered ($k = 1$ to 4), the left bar shows the correlation $corr(i_M, i_{Ht-k})$ while the right bar shows the correlation $corr(i_{Mt-k}, i_H)$. The model implications have been computed by simulating 10000 observations.

6.2 Labor Market Dynamics and the Allocation of Time

The model is able to explain the high volatility of hours worked in the construction sector as well as the positive co-movement with output of both total hours worked, N_T , where $N_T = N_B + N_H$, and hours worked in the construction sector, N_H . As shown by Davis and Heathcote (2005) however, hours worked in both the business and the construction sector are strongly procyclical and explaining this positive co-movement is a challenge for standard models.

To illustrate this point, Table 6 reports the correlation between output and hours worked in the case without housing supply restrictions, $\epsilon_H = 0$. The two capital adjustment costs parameters, ϵ_{k_M} and ϵ_{k_H} , are kept at 3.24 and the correlation with output of hours worked in the business and in the construction sector are denoted $\rho(N_B, y_T)$ and $\rho(N_M, y_T)$.

Table 6: Hours Worked

	Data	$\epsilon_H = 0$	$\epsilon_H = 3.24$
$\rho(N_B, y_T)$	0.86	-0.96	0.99
$\rho(N_H, y_T)$	0.76	0.99	0.99

This Table illustrates that a model with capital adjustment costs but without building restrictions would not be able to explain the procyclicality of hours worked in the business sector. While both sectors are equally penalized by capital adjustment costs, the construction sector is less affected by the externality because it is more labor intensive. In response to a positive shock for instance, it would be optimal to reallocate labor to the construction sector and to decrease hours worked in the business sector. A model without building restrictions would therefore generate a negative co-movement between business hours and output which would be at odd with the data.

Housing-supply restrictions reduce the attractiveness of the construction sector and the comparative advantage provided by high labor intensity. The mechanism is similar to the case studied by van Nieuwerburgh and Weill (2010), where a tightening in housing-supply regulation induces workers to move out. In our case, this is the perfect mobility between sectors which enables workers to escape housing-supply regulation by increasing hours worked in the business sectors. Introducing building restrictions is therefore key to explain the positive co-movement of hours worked and output across sectors.

Not surprisingly, the rather extreme assumption of perfect mobility of labor across the two sectors implying that $w_B = w_H$ is rejected by the data. Wages in the construction sector are more volatile and less correlated with output than wages in the business sector. The model also fails to capture the low correlation between wages in the two sectors and output. As far as the cyclicity of wages is concerned, as shown by Christiano and Eichenbaum (1992), introducing preference shocks usually helps to overcome this problem, typical of real business cycle models.

6.3 House Prices and Housing Supply Restrictions

As far as the volatility of house prices is concerned, our results show that a model able to match the equity premium has no difficulty in generating highly volatile movements in house prices. This point is illustrated in Table 7 which reports how the standard deviation of housing market variables is affected by changes in the housing-supply adjustment costs parameter, ϵ_H . To isolate the impact of housing supply restrictions, the two capital adjustment costs parameter ϵ_{k_H} and ϵ_{k_M} are kept at their benchmark value 3.24. Compared to Tables 3 and 4, all other parameters are kept constant.

As illustrated in Table 7, increasing housing-supply regulation by increasing ϵ_H generates a dramatic increase in the relative standard deviation of house prices, $\sigma_{p_H}/\sigma_{y_T}$

Table 7: Housing-supply Regulation and House Prices

ϵ_H	0	1.5	3.24	5
$\sigma_{p_H}/\sigma_{y_T}$ (<i>Data</i> : 4.01)	1.0	5.74	7.45	8.27
$\sigma_{N_H}/\sigma_{y_T}$ (<i>Data</i> : 2.23)	7.8	3.26	1.75	1.06

The adjustment in quantities occurs in the labor market and leads to an equally dramatic reduction in the relative standard deviation of hours worked, $\sigma_{N_H}/\sigma_{y_T}$. Housing-supply regulation amplifies the response of prices and reduces the response of quantities by acting as an adjustment costs on hours worked.

While labor can move freely across sectors, the large quantitative impact of housing-supply restrictions very much depends on the closed economy assumption. As shown by van Nieuwerburgh and Weill (2010), the impact of regulation is smaller in a model with perfect mobility across cities because agents can choose to move out in response to a tightening in regulation.

According to our model, housing-supply regulation alone would not be able explain the high observed volatility of house prices. This point is illustrated in Table 8 which shows how housing-supply regulation affects the volatility of house prices when the habit formation channel is completely switched off.

Table 8: Without Habit Formation¹⁶

ϵ_H	0	1.5	3.24	5	10
$\sigma_{p_H}/\sigma_{y_T}$ (<i>Data</i> : 4.01)	0.68	2.1	2.39	2.53	2.69

In a model without habit, while reducing the elasticity of housing supply still contributes to increase the volatility of house prices, the quantitative impact is substantially smaller. Even with implausibly large housing-supply adjustment costs, the model without habit formation could only explain about two third of the observed house price volatility.

Very high housing-supply adjustment costs would also generate many counterfactual model implications. In the case $\epsilon_H = 10$ for instance, hours worked in the construction sector are countercyclical and about six times less volatile as in the data. These results suggest that it would be difficult to find a plausible explanation for the high volatility of house prices without combining both supply and demand factors.

According to this study, habit formation is therefore an essential part of the explanation. Habits in the mix of total consumption and leisure exacerbates the cost of uncertainty and induces a precautionary demand for housing services. In good times, this precautionary motive pushes up the demand for new homes and, combined with housing-supply regulation, amplifies the increase in house prices.

6.4 Equity Premium and Housing Returns

It would be considerably more difficult to match the equity premium in a model with habit formation and capital adjustment costs, but without housing supply restrictions. To illustrate this point, Table 9 below shows how habit intensity, m , affects the equity premium in a model with very high

¹⁶Compared to Table 7, habit formation have been switched off by setting $m = 1$. As in Table 5, the two capital adjustment costs parameters ϵ_{k_H} and ϵ_{k_M} are kept at their benchmark value 3.24.

capital adjustment costs ($\epsilon_K = \epsilon_{k_M} = \epsilon_{k_H} = 6.25$) but without housing supply restrictions, ($\epsilon_H = 0$).

Table 9: Equity Premium and Building Restrictions

	$m = 0.875$	$m = 0.83$	$m = 0.82$	$m = 0.79$	$m = 0.77$
$E(r_M - r_f)$	1.52	1.56	2.56	2.48	1.25

As shown by Table 7, even with implausibly large capital adjustment costs, it would be difficult to generate an equity premium larger than 2.56% without housing-supply constraints. Introducing housing services into the stochastic discount factor has therefore important asset pricing implications. Housing increases the potential for consumption risk diversification and could in principle generate a significant reduction in the equity premium [Davis and Martin (2009)]. This result suggests that the extent to which housing contributes to the resolution of asset pricing puzzles very much depends on the degree of housing supply restrictions.

Finally, as shown in Table 4, while the model is able to explain the very low autocorrelation of equity returns, it is not possible to simultaneously explain why the autocorrelation of housing returns observed in the data is so high. The fact that the model also over state the volatility of housing returns is another indication of potential model misspecification.

6.5 The Cost of Uncertainty

The central mechanism of this paper relies on the model's ability to generate costly business cycle fluctuations. To illustrate this point, this section studies how uncertainty affects welfare and the equilibrium allocation. The results are then compared with the equilibrium outcome generated by a standard model.

The welfare cost of uncertainty is obtained by firstly simulating an artificial economy subject to exogenous shocks. The outcome of the stochastic economy is then compared with the deterministic case, which corresponds to an economy which has reached its steady state and which is growing at a constant rate along the balanced growth path. The second-order approximation that is used to solve the model [see Adjemian, Juillard, Mihoubi, Perendia and Villemot (2009)] can then be exploited to capture the effect of uncertainty on total welfare, consumption, hours worked, and wages.

Total welfare in the stochastic economy is denoted V_t and is given by:

$$V_t = \frac{1}{1-\sigma} [c_t^\kappa h_t^{1-\kappa} v(L_t) - x_t]^{1-\sigma} + \beta^* E_t V_{t+1}$$

Total welfare in the deterministic case is denoted \bar{V} , and can be computed by solving the steady state of the model. The welfare cost of uncertainty, which is given by $(V_t - \bar{V})/\bar{V}$, measures the percentage loss in welfare due to the introduction of uncertainty. Table 8 below illustrates the impact of habit formation and capital adjustment costs on the equity premium and on the equilibrium outcome.

Table 10: Welfare Loss and Impact of Uncertainty on Consumption, Hours Worked, and Wages¹⁷.

	Benchmark $m = 0.87, \epsilon = 3.2$	No Frictions $m = 1, \epsilon = 0$
$(c_T - \bar{c}_T)/\bar{c}_T$	14	0.94
$(N_T - \bar{N}_T)/\bar{N}_T$	10.3	0.18
$(w - \bar{w})/\bar{w}$	11.6	1.01
$(V_t - \bar{V})/\bar{V}$	1.74	0.27
$E(r_M - r_f)$	6.19	0.01

Compared to an economy without shocks and growing at a constant rate along the balanced growth path, uncertainty reduces welfare by less than 2 percent in the benchmark model ($m = 0.875, \epsilon = 3.24$). Without habit formation and adjustment costs ($m = 1, \epsilon = 0$) the model would generate a tiny equity premium and the welfare cost of uncertainty would be considerably smaller.

Finally, Table 8 reports the percentage increase in total consumption, c_T , where $c_T = c_{Mt}^\kappa h_t^{1-\kappa}$, hours worked, and wages that would be necessary to make a representative consumer indifferent between a smooth, non-fluctuating economy and one that is subject to business cycles. The annualized percentage increase in consumption, hours, and wages induced by uncertainty are denoted $(c_T - \bar{c}_T)/\bar{c}_T$, $(N_T - \bar{N}_T)/\bar{N}_T$ and $(w - \bar{w})/\bar{w}$.

¹⁷ c_T, N_T, w are the expected levels of respectively consumption, hours and wages that will have to be supplied and paid in an economy subject to random shocks. \bar{c}_T, \bar{N}_T and \bar{w} can be interpreted as the certainty equivalents while $c_T - \bar{c}_T, N_T - \bar{N}_T$ and $w - \bar{w}$ can be seen as the risk premium that agents would be ready to pay to avoid the lottery. The compensation for risk have been expressed in annualized percent.

As shown in Table 10, in the benchmark model, the uncertainty caused by business cycle fluctuations has a considerable impact on behaviors. Agents would for instance be ready to sacrifice more than 11% of their annual income, 14% of their annual consumption¹⁸, and would accept to reduce hours worked by more than 10% to eliminate the uncertainty caused by business cycle fluctuations.

7 Conclusion

The recent episode of financial distress has revived the debate over whether monetary policy should react to fluctuations in house prices. While this debate has been ongoing for many years, the answer to this question still very much depends on central banks' ability to distinguish between "excessive" and "fundamentally driven" movements in house prices.

Our analysis suggests that ignoring factors which affect the elasticity of housing supply, such as housing-supply regulation, may lead central banks to overstate the potential for house price misalignment. As we have shown in section 4, in a model with housing supply constraints, the value of a house can deviate from the standard infinite discounted sum formula. Moreover, a model with building restrictions and habit formation can generate "fundamentally driven" fluctuations in house prices which can be very large.

Finally, the equilibrium value of a house is closely linked to the model's financial market implications. Versions which failed to generate a plausible equity premium also generated smaller house price fluctuations. This result illustrates the importance of using well-specified stochastic discount factors. Checking the robustness of the discount factor that is assumed by confronting additional model implications to the data may contribute to reduce the risk of misspecification.

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¹⁸This number cannot be compared to the consumption equivalent calculation proposed by Lucas (2003). It is not clear how to perform this calculation in a model with internal habit formation and leisure.

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9 Data Appendix

Variable	Source
y_T	St-Louis Fed, GDPC96 (1947-2009)
c_M	St-Louis Fed, PCNDGC96+PCESVC96 (1947-2009)
i_M	St-Louis Fed, NRIPDC96 (1947-2009)
i_H	St-Louis Fed, PRFIC96 (1947-2009)
N_T	St-Louis Fed, USPRIV (1947-2009)
N_H	St-Louis Fed, USCONS (1947-2009)
w_B	St-Louis Fed, RCPHBS (1947-2009)
w_H	St-Louis Fed, AHECONS (1947-2009)
p_{Et}	R. Shiller, Real equity prices (1871-2009)
d_t	R. Shiller, Real earnings (1871-2009)
p_{Ht}	R. Shiller, case-Shiller 15 index (1987-2009)
z_H	Housing CPI, Haver Analytics (1967-2009)
$E(r_M - r_f), \sigma(r_M)$	Piazzesi, Schneider and Tuzel (2007)
$E(r_H - r_f), \sigma(r_H)$	Piazzesi, Schneider and Tuzel (2007)
$E(r_f), \sigma(r_f)$	Piazzesi, Schneider and Tuzel (2007)

10 Solution Method

The model is solved using perturbation methods. The second-order approximation around the steady state, the theoretical moments, and the impulse responses are computed using the software dynare [see Adjemian, Juillard, Mihoubi, Perendia and Villemot (2009)].

11 The Competitive Equilibrium

In the economy without externalities, the competitive equilibrium and the problem of the social planner are equivalent. Asset pricing equations can be derived by considering a competitive equilibrium where households are renters and where the representative firm builds new homes and rents housing services.

11.1 Households

$$\begin{aligned}
L = E_0 & \left\{ \sum_{t=0}^{\infty} \frac{1}{1-\sigma} \beta^{*t} [c_{Mt}^{\kappa} h_t^{1-\kappa} v(L_t) - x_t]^{1-\sigma} \right. \\
& + \sum_{t=0}^{\infty} \beta^{*t} \lambda_t [w_{Mt} N_{Mt} + w_{Ht} N_{Ht} + S_t d_t \\
& \quad \left. - z_{Ht} h_t - c_{Mt} - p_{Et} [S_{t+1} - S_t]] \right. \\
& \left. + \sum_{t=0}^{\infty} \beta^{*t} \psi_t [m x_t + (1-m) [c_{Mt}^{\kappa} h_t^{1-\kappa} v(L_t)] - \gamma x_{t+1}] \right\}
\end{aligned}$$

First-order conditions:

To simplify notation, we define:

$$u_t = c_{Mt}^{\kappa} h_t^{1-\kappa} v(L_t) - x_t$$

c_{Mt} :

$$[\kappa c_{Mt}^{\kappa-1} h_t^{1-\kappa} v(L_t)] u_t^{-\sigma} + [\kappa c_{Mt}^{\kappa-1} h_t^{1-\kappa} v(L_t)] (1-m) \psi_t = \lambda_t$$

N_{Mt} :

$$[c_{Mt}^{\kappa} h_t^{1-\kappa} v'(L_t)] u_t^{-\sigma} + [c_{Mt}^{\kappa} h_t^{1-\kappa} v'(L_t)] (1-m) \psi_t = \lambda_t w_{Mt}$$

N_{Ht} :

$$[c_{Mt}^{\kappa} h_t^{1-\kappa} v'(L_t)] u_t^{-\sigma} + [c_{Mt}^{\kappa} h_t^{1-\kappa} v'(L_t)] (1-m) \psi_t = \lambda_t w_{Ht}$$

h_t :

$$z_{Ht} \lambda_t = [(1-\kappa) c_{Mt}^{\kappa} h_t^{-\kappa} v(L_t)] u_t^{-\sigma} + [(1-\kappa) c_{Mt}^{\kappa} h_t^{-\kappa} v(L_t)] (1-m) \psi_t$$

x_{t+1} :

$$\psi_t = m \beta E_t \psi_{t+1} - \beta E_t u_{t+1}^{-\sigma}$$

λ_t :

$$w_{Mt}N_{Mt} + w_{Ht}N_{Ht} + S_t d_t = z_{Ht}h_t + c_{Mt} + p_{Et} [S_{t+1} - S_t]$$

ψ_t :

$$mx_t + (1 - m) [c_{Mt}^\kappa h_t^{1-\kappa} v(L_t)] - \gamma x_{t+1} = 0$$

11.2 The Firm

Managers maximize the value of the firm by solving the following dynamic optimization program:

$$\text{Max } E_0 \sum_{t=0}^{\infty} \beta^{*t} \frac{\lambda_t}{\lambda_0} d_t$$

such that:

$$d_t = y_{Mt} + z_{Ht}h_t - w_{Mt}N_{Mt} - w_{Ht}N_{Ht} - i_{KHt} - i_{Mt}$$

$$\begin{aligned} &+ p_{Ht} \left[\phi \left(\frac{y_{Ht}}{h_t} \right) h_t + (1 - \delta_H)h_t - \gamma h_{t+1} \right] + q_{Mt} \left[(1 - \delta_M)k_{Mt} + \phi \left(\frac{i_{Mt}}{k_{Mt}} \right) k_{Mt} - \gamma k_{Mt+1} \right] \\ &+ q_{KHt} \left[(1 - \delta_{KH})k_{KHt} + \phi \left(\frac{i_{KHt}}{k_{KHt}} \right) k_{KHt} - \gamma k_{KHt+1} \right] \end{aligned}$$

First-order conditions:

N_{Mt} :

$$w_{Mt} = (1 - \alpha) \frac{y_{Mt}}{N_{Mt}}$$

N_{Ht} :

$$w_{Ht} = p_{Ht} \phi' \left(\frac{y_{Ht}}{h_t} \right) (1 - \varphi) \frac{y_{Ht}}{N_{Ht}}$$

i_t^M :

$$1 = q_{Mt} \phi' \left(\frac{i_{Mt}}{k_{Mt}} \right)$$

i_t^{KH} :

$$1 = q_{KHt} \phi' \left(\frac{i_{Ht}}{k_{Ht}} \right)$$

k_{Ht+1} :

$$\begin{aligned} \lambda_t q_{KHt} = \beta E_t \lambda_{t+1} q_{KHt+1} & \left\{ (1 - \delta_{KH}) + \phi \left(\frac{i_{Ht+1}}{k_{Ht+1}} \right) - \phi' \left(\frac{i_{Ht+1}}{k_{Ht+1}} \right) \frac{i_{Ht+1}}{k_{Ht+1}} \right\} \\ & + \beta E_t p_{Ht+1} \phi' \left(\frac{y_{Ht+1}}{h_{t+1}} \right) \varphi \frac{y_{Ht+1}}{k_{Ht+1}} \end{aligned}$$

k_{Mt+1} :

$$\lambda_t q_{Mt} = \beta E_t \lambda_{t+1} q_{Mt+1} \left\{ (1 - \delta_M) + \phi \left(\frac{i_{Mt+1}}{k_{Mt+1}} \right) - \phi' \left(\frac{i_{Mt+1}}{k_{Mt+1}} \right) \frac{i_{Mt+1}}{k_{Mt+1}} \right\} + \beta E_t \lambda_{t+1} \alpha \frac{y_{Mt+1}}{k_{Mt+1}}$$

h_{t+1} :

$$\lambda_t p_{Ht} = \beta E_t \lambda_{t+1} \left[\left((1 - \delta_H) + \phi \left(\frac{y_{Ht+1}}{h_{t+1}} \right) - \phi' \left(\frac{y_{Ht+1}}{h_{t+1}} \right) \frac{y_{Ht+1}}{h_{t+1}} \right) p_{Ht+1} + z_{Ht+1} \right]$$

λ_t :

$$d_t = y_{Mt} + z_{Ht} h_t - w_{Mt} N_{Mt} - w_{Ht} N_{Ht} - i_{KHt} - i_{Mt}$$

q_{Mt} :

$$(1 - \delta_M) k_{Mt} + \phi \left(\frac{i_{Mt}}{k_{Mt}} \right) k_{Mt} - \gamma k_{Mt+1} = 0$$

q_{KHt} :

$$(1 - \delta_{KH}) k_{Ht} + \phi \left(\frac{i_{Ht}}{k_{Ht}} \right) k_{Ht} - \gamma k_{Ht+1} = 0$$

p_{Ht} :

$$(1 - \delta_H) h_t + \phi \left(\frac{y_{Ht}}{h_t} \right) h_t - \gamma h_{t+1} = 0$$

Introducing Leverage

$$d_t = y_{Mt} + z_{Ht}h_t - w_{Mt}N_{Mt} - w_{Ht}N_{Ht} - i_{KHt} - i_{Mt} + p_{Bt}\gamma b_{t+1} - b_t$$

where:

$$\tau = \frac{b_t}{k_{Tt}}$$

and:

$$k_{Tt} = k_{Mt} + k_{Ht} + h_t$$