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**Abstract**

We augment a closed-economy DSGE model with collateral constraints tied to real estate values by incorporating the time-to-build phenomenon in the housing construction sector. Adding construction sector delays significantly improves business cycle properties of the model relative to the versions with no time-to-build delays or with permanently fixed housing stock. We also find that in the presence of construction lags adding housing prices to the central bank policy function increases aggregate welfare in the economy by up to 0.3 percent of consumption. This result is robust to several specifications of the Taylor rule and to changes in key parameter values.

Key words: Housing prices, housing construction, time-to-build, welfare.

JEL classification: E32, E44, E52, E58.

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## 1 Introduction

In many industrialized countries, the last two decades have been characterized by a surge, followed by a sharp downward adjustment, of housing prices. Insofar as developments in the housing sector have a significant effect on the rest of the economic activity (as has been clearly demonstrated by the current financial crisis), many researchers have attempted to elucidate the linkages between real estate market and other sectors of the economy.[1] Of particular interest is the question of whether monetary policy should react to fluctuations in housing prices in order to improve consumer welfare.[2] However, very few authors in either strand of the literature have explicitly modeled both sides of the housing market, with the majority of papers focusing only on housing demand. The risk of such simplified approach is that policy implications, especially prescriptions for central banks, may be

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[1] A non-exhaustive list of recent work includes Campbell and Cocco (2007), Carstensen et al. (2009), Davis and Heathcote (2005), Goodhart and Hofmann (2007), Iacoviello (2005) and Monacelli (2009).

[2] See, for example, Bernanke and Gertler (2001), Cecchetti (2007), Gilchrist and Leahy (2002) and Roubini (2006).

misleading, as we will demonstrate below. Our main thesis is that incorporating construction sector and, in particular, the time-to-build phenomenon, into economic models is crucial for understanding housing price dynamics and for evaluating the appropriateness of central bank responses to the latter.

According to industry reports, commercial and residential construction projects often take multiple months (or even years) to complete, and most residential home construction is finished before a buyer is found.[3] Consequently, housing construction sector cannot respond instantaneously to changes in demand for real estate.[4] Unfortunately, very few papers on the housing market incorporate these facts into the models. While the time-to-build technology in the production function has been the topic of numerous papers (see, for example, Kydland and Prescott (1982)), to date only Gomme et al. (2001) has explored time delays in residential investment; the authors demonstrate that adding delays to a household-production real business cycle (RBC) model greatly improves its ability to replicate data on household and market capital stock expenditures. Despite these findings, many recent papers, including Aoki, Proudman and Vlieghe (2004), Iacoviello and Neri (2010) and Monacelli (2009) model the construction sector without any time delays.[5]

Based on these observations, we fill the gap in the literature by building a New Keynesian dynamic stochastic general equilibrium (DSGE) model with housing construction sector characterized by long delays between the commencement and completion of any given project. As a result, the construction sector incurs the risk to its profits from unexpected future housing price fluctuations, and therefore must make investment decisions (which affect the future supply of housing) in a forward-looking manner. We show that such delays lead to lower responsiveness of housing supply following economic shocks, to higher housing price volatility and to reduced welfare of consumers. We also show that incorporating time-to-build feature into the construction sector is critical in matching the business cycle properties of housing market variables.

We then turn to the question of monetary policy conduct. Most modern central banks have price stability as their primary goal; however, generally they do not explicitly target housing prices. Recently, several papers have pursued the question of the transmission process between housing prices and monetary policy. Bernanke and Gertler (2001) famously postulate that the central bank should only react to housing prices insofar as they help to predict future inflation. Gilchrist and Leahy (2002) consider three general arguments for including asset prices in monetary policy rules: asset prices belong in a measure of the price level, asset prices forecast inflation, and there may exist structural links between asset prices, consumption and investment. While they conclude that the third argument is important, the authors find that it does not alone provide a reason for basing monetary policy on asset prices. Iacoviello (2005) studies the improvements in inflation-output gap variance frontiers and finds only marginal benefits from having central bank respond to housing prices.

In order to assess potential gains to consumers from stabilizing housing prices, we modify the policy rule followed by the central bank by including in it real housing appreciation and compute the resulting changes in welfare.[6] We find that, present non-zero lags in the construction sector, including housing prices in the monetary policy rule is welfare enhancing. This result is robust

[3] First Research Industry Profile - Residential Real Estate Construction, Quarterly Update, 2/23/2009, and First Research Industry Profile - Commercial Construction Contractors, Quarterly Update, 2/23/2009.

[4] Some qualitative support for this phenomenon is also offered in Esteban and Altuzarra (2008).

[5] One exception is Davis and Heathcote (2005), who include a one-period (in their model, a year) construction delay, but do not study its impact on the dynamics of the model.

[6] The only paper we are aware of that explicitly computes changes household welfare is Mendicino and Pescatori (2008); the authors do not find any welfare improvements from housing price stabilization.

to several specifications of the Taylor rule and to changes in parameter values. The key finding is explained both by the presence of houses in consumer utility functions and by the fact that collateralized borrowing of credit-constrained households depends crucially on the expected value of their future real estate holdings. Long delays in construction decrease the responsiveness of housing supply and increase fluctuations of housing prices and consequently of borrowing limits. The central bank is able to increase total welfare by reacting to fluctuations in housing prices. Moreover, we show that welfare gains are non-linear in the duration of construction lags; the gains are very close to zero in the versions of the model with no lags in construction, and with no construction sector (the two setups used widely in existing literature).

The rest of the paper is structured as follows: the theoretical model is presented in section 2; section 3 discusses calibration; section 4 presents the results of our simulations and robustness exercises. Finally, concluding remarks are contained in section 5.

# 2 The Model

The core of our model is based on Iacoviello (2005). The closed economy is populated by two types of infinitely lived households (patient and impatient) and by entrepreneurs; each group is of measure 1. All agents consume real estate and all varieties of local goods, the latter being produced by perfectly competitive entrepreneurs using labor, real estate and capital. These goods are then resold by retailers at a mark-up. Households offer their labor services to labor unions, which then resell the services to employers at a higher rate. Retail prices and wages are sticky à la Calvo (1983). The central bank sets the interest rate in response to inflation and output gap fluctuations.

The new feature is the addition of the housing construction sector, which uses labor and land and borrows from consumers in order to build and sell houses to households and entrepreneurs, thus adding dynamics to the supply side of the real estate market. Labor is fully mobile between the two sectors of the economy: goods production and housing construction.

## 2.1 Households

We model two types of households, differentiated by their intertemporal discount factor $\beta$: patient ($\beta^p$) and impatient ($\beta^m$), with $0 < \beta^m < \beta^p < 1$. Each type of household is of measure one; notationally, superscript $p$ will indicate variables pertaining to patient households, and superscript $m$ will denote variables of impatient households.

A representative household maximizes expected lifetime utility

$$U_t^j = E_0 \sum_{t=0}^{\infty} \left[\beta^j\right]^t \left\{ \frac{\left[C_t^j\right]^{1-\Theta}}{1-\Theta} - \frac{\left[L_t^j\right]^{1+\chi}}{1+\chi} + \gamma \frac{\left[H_t^j\right]^{1-\Theta}}{1-\Theta} \right\}, \tag{1}$$

for $j \in \{p, m\}$.[7] Here $C_t^j$ denotes the household's consumption of the composite good, which is aggregated from home varieties using the Dixit-Stiglitz aggregator defined in section 2.3. $H_t^j$ denotes the stock of housing (real estate). Households supply differentiated labor services $L_t^j$ to entrepreneurs and the construction sector via labor unions, described below.

[7] Following Woodford (2003), Chapter 3, we model monetary policy as directly targeting interest rates and therefore drop real balances from the consumer utility function.

Each patient household faces the following budget constraint:

$$Q_t \Delta H_t^p + \xi_{h,t}^p + P_t C_t^p - B_t^p + P_t I_t^k + \xi_{K,t} = W_t^p L_t^p - R_{t-1} B_{t-1}^p + R_{K,t} K_{t-1} + D_t^r + D_t^u + D_t^c \quad (2)$$

The first two terms on the left-hand side capture the expenditure on additional housing plus the adjustment costs $\xi_{h,t}^j \equiv \frac{\phi}{2}\left[\frac{\Delta H_t^j}{H_{t-1}^j}\right]^2 Q_t H_{t-1}^j$, $j \in \{p, m\}$. $B_t^j$ represents household's borrowing, given the nominal interest rate $R_t$.[8] Patient households own capital $K_t$, which they rent out to entrepreneurs at a market rate $R_{K,t}$ and which evolves according to

$$K_t = (1-\delta)K_{t-1} + I_t^k \quad (3)$$

Here, the investment good $I_t^k$ has the same composition as consumption. Capital accumulation is subject to adjustment costs $\xi_{K,t} \equiv P_t \frac{\psi}{2}\left[\frac{I_t^k}{K_{t-1}} - \delta\right]^2 K_{t-1}$. Finally, $D_t^r$, $D_t^u$ and $D_t^c$ are profits of retailers, labor unions and the construction sector, respectively (described below).

Patient households maximize utility (1) subject to the constraints (2) and (3) by choosing labor effort $L_t^p$, consumption $C_t^p$, and investment positions $B_t^p$, $\Delta H_t^p$ and $I_t^k$. The first order conditions for this problem are described in Appendix B.

Impatient households' budget constraint is

$$Q_t \Delta H_t^m + \xi_{h,t}^m + P_t C_t^m + R_{t-1} B_{t-1}^m = W_t^m L_t^m + B_t^m \quad (4)$$

Impatient households face an additional credit constraint that limits the amount of borrowing, which cannot exceed a fraction $l^m$ of the expected discounted value of their real estate holdings:

$$B_t^m \leq l^m E_t\left[\frac{Q_{t+1} H_t^m}{R_t}\right]$$

where $l^m$ is assumed to be fixed and known. We assume that $\beta^m < \beta^p$, which implies that impatient households discount future more heavily than the patient households. This guarantees that the former are constrained in and around the steady state. Specifically, the fact that $(1/\beta^m) > R_t$ causes the Lagrange multiplier on the credit constraint to be greater than zero. Therefore, the borrowing constraint will hold with equality:

$$B_t^m = l^m E_t\left[\frac{Q_{t+1} H_t^m}{R_t}\right] \quad (5)$$

Mortgage loans are refinanced each period.

Impatient households maximize utility (1) subject to the constraints (4) and (5) by choosing labor effort $L_t^m$, consumption $C_t^m$, and investment positions $B_t^m$ and $\Delta H_t^m$. The corresponding first order conditions are listed in Appendix B.

## 2.2 Entrepreneurs

Each country has a continuum of entrepreneurs on the interval $[0,1]$. At time $t$, each entrepreneur uses the stock of real estate $H_t^e$ and hires labor inputs $N_{e,t}^p$ and $N_{e,t}^m$ and capital stock $K_{t-1}$ at the corresponding rates $W_t^p$, $W_t^m$ and $R_{K,t}$ to produce one of the varieties of the domestic good:

$$Y_t = A_t \left[K_{t-1}^e\right]^{\mu} \left[N_{e,t}^p\right]^{\alpha(1-\mu-v)} \left[N_{e,t}^m\right]^{(1-\alpha)(1-\mu-v)} \left[H_{t-1}^e\right]^{\nu} \quad (6)$$

[8] We assume that $\beta^p$ is sufficiently high to induce patient households to save in the steady state, while impatient households will choose to borrow.

Here $A_t$ denotes the level of productivity enjoyed by all the entrepreneurs at time $t$, which evolves according to the following autoregressive process:

$$\ln A_t = \rho_a \ln A_{t-1} + \varepsilon_t^a$$

$N_{e,t}^p$ and $N_{e,t}^m$ are the patient and impatient household labor efforts, and $\alpha$ measures the relative size of each group.[9]

Each entrepreneur maximizes

$$E_0 \sum_{t=0}^{\infty} (\beta^e)^t \left\{ \frac{[C_t^e]^{1-\Theta}}{1-\Theta} \right\} \tag{7}$$

subject to the following flow of funds constraint:

$$P_t^e Y_t + B_t^e = P_t C_t^e + Q_t \Delta H_t^e + \xi_{h,t}^e + W_t^p N_{e,t}^p + W_t^m N_{e,t}^m + R_{t-1} B_{t-1}^e + R_{K,t} K_{t-1}, \tag{8}$$

where $\xi_{h,t}^e \equiv \frac{\phi}{2} \left[ \frac{\Delta H_t^e}{H_{t-1}^e} \right]^2 Q_t H_{t-1}^e$ captures housing adjustment costs. $B_t^e$ and $C_t^e$ denote the entrepreneur's borrowing and consumption, and $P_t^e$ is the wholesale price of output. Similar to the impatient households, entrepreneurs are also restricted in their borrowing due to enforceability problems. The amount of borrowing cannot exceed a fixed fraction of the discounted value of their real estate holdings:

$$B_t^e \leq l^e E_t \left[ \frac{Q_{t+1} H_t^e}{R_t} \right] \tag{9}$$

In the presence of credit constraints, entrepreneurs can choose to postpone consumption and quickly accumulate enough capital so that their credit constraint becomes nonbinding. In order to make sure that entrepreneurial self-financing does not arise, we assume that entrepreneurs discount the future more heavily than patient households: $\beta^e < \beta^p$. As for impatient households, this guarantees that the credit constraint is binding in and around the steady state.

Entrepreneurs maximize (7) subject to (6), (8) and (9); the solution to the entrepreneurs' problem can be found in Appendix B.

## 2.3 Retailers and Unions

In order to introduce nominal rigidities, we model a retail sector following Bernanke et al. (1999). Each of the monopolistically competitive retailers (indexed by $r$ on the interval $[0,1]$) buys one of the varieties produced by the entrepreneurs and resells it to the consumers and investors at the optimally determined price $P_t(r)$. These varieties are bundled into a composite good using the Dixit-Stiglitz aggregator

$$Y_t = \left[ \int_0^1 Y_t(r)^{\frac{\sigma-1}{\sigma}} dr \right]^{\frac{\sigma}{\sigma-1}}$$

[9] Following Iacoviello (2005), we let hours of the two households enter the production function in a Cobb-Douglas fashion. This assumption implies complementarity across the labor skills of the two groups and allows us to obtain closed-form solutions for the steady state of the model. This form for the production function is also motivated by the fact that credit-constrained households typically have low incomes. Hence, we parameterize $\alpha$ so that their share in labor income is lower than that of the patient households.

where $\sigma > 1$. This composite good can then be used for consumption or investment. The price of the bundle is given by $P_t = \left[\int_0^1 P_t(r)^{1-\sigma}dr\right]^{\frac{1}{1-\sigma}}$, and therefore demand for each of the varieties is $Y_t^d(r) = \left[\frac{P_t(r)}{P_t}\right]^{-\sigma} Y_t^d$. Here $Y_t^d$ is the aggregate demand for the bundles from households and investors.

As in Calvo (1983), retailers reset their prices each period with a constant probability $(1-\omega_p)$; otherwise, the old prices remain in effect. If a retailer $r$ gets to announce a new price in period $t$, she chooses $\tilde{P}_t(r)$ to maximize her expected discounted future profits

$$E_t \sum_{j=t}^{\infty} [\beta^p \omega_p]^{j-t} \frac{\vartheta_j^p}{\vartheta_t^p} \left\{ \left[\tilde{P}_t(r) - P_j^e\right] Y_j^d(r) \right\},$$

where $\vartheta_t^p$ is the patient households' marginal utility of consumption: $[\vartheta_t^p]^{-1} = [C_t^p]^{\Theta} P_t$.

Given the price-setting behavior of individual retailers, the aggregate price index of the consumption bundle can be written as

$$P_t^{1-\sigma} = (1-\omega_p)\tilde{P}_t^{1-\sigma} + \omega_p P_{t-1}^{1-\sigma}$$

Wage rigidity is modeled analogously.[10] Households sell their labor services to unions, who then bundle and resell them to entrepreneurs and construction sector at the optimally determined rate $\tilde{W}_t^j(u)$ for $j \in \{p, m\}$. Labor varieties are bundled into a composite good according to $L_t^j = \left[\int_0^1 L_t^j(u)^{\frac{\phi-1}{\phi}} du\right]^{\frac{\phi}{\phi-1}}$. Labor unions reset their wages each period with a constant probability $(1-\omega_w)$; otherwise, the old wages remain in effect. Similar to the price of the bundle of goods, the expression for aggregate wage can be written as

$$\left[W_t^j\right]^{1-\phi} = (1-\omega_w)\left[\tilde{W}_t^j\right]^{1-\phi} + \omega_w \left[W_{t-1}^j\right]^{1-\phi}$$

## 2.4 Housing Construction

The perfectly competitive domestic construction sector adds to the stock of real estate by using labor of patient and impatient households and (a fixed amount of) land $T$, which it owns, to produce new housing:

$$I_t^h = \left[N_{c,t}^p\right]^{\alpha(1-\eta)} \left[N_{c,t}^m\right]^{(1-\alpha)(1-\eta)} T^{\eta} \tag{10}$$

Land in the production function serves as an adjustment cost to residential investment; we assume that land is used as a service so that the amount of it available for production does not diminish over time.[11]

The construction sector cannot respond instantaneously to an increase in demand for housing (due, for example, to a positive development in the economy) since several steps are needed before a new dwelling can be supplied in the market: obtaining permission for the development, securing the loan, assembling the construction site, finalizing the project, and finally marketing the property.

[10] Modeling wage rigidity is necessary to generate a decline in residential investment following a domestic interest rate shock (observed in the data). This result is in line with findings of Barsky, House and Kimball (2007) and Iacoviello and Neri (2009).

[11] An alternative setup (that would offer qualitatively similar results) is to introduce capital and/or investment adjustment costs into the production function.

Because of such delays between the commencement of a project and its completion, we assume that the construction sector sells the houses begun in period $t$, $I_t^h$, with a $k$-period lag, in effect taking on the risk of unexpected future fluctuations in the price of real estate. The profits (which may deviate from zero because of this risk) therefore take the form

$$D_t^c = Q_t I_{t-k}^h + B_t^c - W_t^p N_{c,t}^p - W_t^m N_{c,t}^m - R_{t-1} B_{t-1}^c \tag{11}$$

Here we assume that the price $Q_t$ adjusts to clear the market, so that all houses available for sale in period $t$ are bought by the consumers and entrepreneurs.

Due to uneven cash flow and inherent risk associated with real estate development, construction sector frequently relies on borrowed funds.[12] In our model, the amount of borrowing available to the construction sector is limited to a fraction of the present discounted value of the houses that will be ready for sale in the next period:

$$B_t^c = l^c E_t \left[ \frac{Q_{t+1} I_{t+1-k}^h}{R_t} \right] \tag{12}$$

Construction firms maximize (11) subject to (10) and (12) by choosing $B_t^c$, $N_{c,t}^p$ and $N_{c,t}^m$. The profits then get rebated lump-sum to the patient households. The resulting first order conditions are described in Appendix B.

The aggregate stock of housing (available to both types of households and the entrepreneurs) evolves according to the following transition equation:

$$H_{t+1} = \left(1 - \delta^h\right) H_t + I_{t+1-k}^h$$

## 2.5 The Central Bank

We assume that the central bank credibly targets inflation and output gap by adopting a variation of the Taylor rule commonly used in the monetary literature:

$$\ln(R_t) = (1-\rho_i)\ln\left(\overline{R}\right) + \rho_i \ln(R_{t-1}) + (1-\rho_i)\left[\rho_\pi \pi_t + \rho_y y_t^{gap}\right] \tag{13}$$

$\overline{R} = \frac{1}{\beta^p}$ is the steady state level of the interest rate, and $\rho_i$ measures the degree of interest rate inertia. As a matter of robustness check, we study the model behavior under two different specifications of output gap: first as a deviation of output from its flexible price level, and then as a deviation from its previous period level. We also verify the results by setting $\rho_y = 0$.[13]

## 2.6 Measure of National Welfare

A natural (and commonly used) measure of the national welfare is the aggregate utility (or value function) of all the domestic households:

$$U_t = U_t^p + U_t^m + U_t^e,$$

[12] First Research Industry Profile.

[13] We were unable to achieve numerical convergence in the model with flexible output gap for construction lag lengths of 1 or 8, or for reparameterizations of the benchmark model. However, the qualitative welfare results are the same regardless of the definition of output gap (and even in the version with no output gap); we will use the more stable version with the output growth gap in the discussion below.

where $U_t^p$ and $U_t^m$, both described by (1), represent the total utility of patient and impatient households, respectively, and $U_t^e$ (from equation (7)) is the utility of entrepreneurs.[14]

These components of the value function will allow us to make quantifiable comparisons of consumer and entrepreneur welfare across different specifications of the model. To see how this can be done, let $\tilde{U}_t^p$ correspond to some benchmark specification of the economy (for example, with no price rigidity, so $\omega_p = 0$) and let $U_t^p$ be the utility of patient households from a different specification (to follow the above example, let $\omega_p = 0.5$). Then, in the case of log utility, the difference, denoted by $\epsilon^p$, between the two value functions

$$\epsilon^p \equiv U_t^p - \tilde{U}_t^p$$

can be interpreted as cost to patient households, expressed as percent of their steady state consumption, of moving away from the benchmark specification to (in the above example) the economy with nominal rigidities.[15] Analogously, $\epsilon^m \equiv U_t^m - \tilde{U}_t^m$ and $\epsilon^e \equiv U_t^e - \tilde{U}_t^e$ will allow us to compare the welfare of impatient households and entrepreneurs in the two scenarios. We thus can draw inferences not only about the total welfare of the economy ($\epsilon \equiv \epsilon^p + \epsilon^m + \epsilon^e$), but also about welfare trade-offs between the three groups of agents.

### 2.7 Equilibrium

The following market clearing conditions complete the description of the model.

$$\begin{aligned} Y_t &= C_t^p + C_t^m + C_t^e + I_t^k + \xi_{K,t} && (14)\\ L_t^p &= N_{e,t}^p + N_{c,t}^p && (15)\\ L_t^m &= N_{e,t}^m + N_{c,t}^m && (16)\\ -B_t^p &= B_t^m + B_t^e + B_t^c && (17)\\ H_t &= H_t^p + H_t^m + H_t^e && (18) \end{aligned}$$

Equilibrium in the economy is defined by (14)-(18) and the first order conditions of the agents, given the form of monetary policy rule described above. The model was solved numerically using Dynare (see Collard and Juillard (2003)). First order approximations were used to compute moments, variance decompositions and impulse response functions presented below; value functions were calculated using second-order approximations to the model.

## 3 Estimation and Calibration

The model is calibrated to Spain; each time period corresponds to one quarter. Table 1 summarizes the key parameters of our model. Many of these values are common in the RBC/monetary literature; a few others merit further description.

The values of the first group of the model parameters are fairly standard; we set $\beta^p = 0.99$, $\Theta = 1$, $\delta = 0.03$, and $\mu = 0.3$. Next, we calibrate elasticities of labor supply and varieties

[14] Since the total measure of patient households is 1, and each is representative in its choices of consumption, labor and housing, the total utility of the group is equal to the utility of each individual household. The same argument holds for impatient households and entrepreneurs.

[15] See Mykhaylova (2009) for details.

| Parameter | Description | Value |
|---|---|---|
| $\Theta$ | Relative risk aversion | 1.00 |
| $\chi$ | Inverse of Frisch labor elasticity | 3.00 |
| $\beta^p$ | Discount factor of patient households | 0.99 |
| $\beta^m$ | Discount factor of impatient households | 0.95 |
| $\beta^e$,$\beta^c$ | Discount factor of entrepreneurs and the construction sector | 0.96 |
| $\gamma$ | Weight on housing services for households | 0.25 |
| $\alpha$ | Income share of patient households | 0.79 |
| $\mu$ | Capital share in the production function | 0.30 |
| $\nu$ | Real estate share in the production function | 0.11 |
| $\delta$ | Capital depreciation rate | 0.03 |
| $\psi$ | Capital adjustment cost | 9.0 |
| $\delta^h$ | Housing depreciation rate | 0.006 |
| $\sigma$ | Elasticity of substitution between goods varieties | 3.90 |
| $\phi$ | Elasticity of substitution between labor varieties | 4.30 |
| $\omega_p$ | Price stickiness | 0.75 |
| $\omega_w$ | Wage stickiness | 0.75 |
| $l^m$ | LTV ratio for impatient households | 0.76 |
| $l^e, l^c$ | LTV ratio for entrepreneurs and the construction sector | 0.27 |

Table 1: Benchmark parameter values

substitution, which we take from a variant of IMF's Global Economy Model (GEM).[16] We set $\chi = 3$, $\sigma = 3.9$ and $\phi = 4.3$ (the latter two resulting in a 35 percent and 30 percent markups of price over marginal cost and wage over labor disutility, respectively).

Next we set the discount factors of impatient households, entrepreneurs and the construction sector. While the values of these parameters have limited effects on the dynamics of the model, it is important to set them such that the credit constraints are binding in and around the steady state. To this end, we fix the discount factor of impatient households $\beta^m$ at 0.95. We assume that the internal rate of return of the entrepreneurs and the construction sector is four times larger than the equilbirium real rate; therefore, we set $\beta^e = \beta^c = 0.96$. As a first pass, we follow Iacoviello and Neri (2010) and set $\alpha$, the income share of patient households, to 0.79, and the housing adjustment cost parameters to 0.

The parameter $\gamma$ controls the stock of residential housing relative to annual output: setting $\gamma = 0.25$ fixes the ratio at around 400 percent, in line with the data from the Spanish housing market (see Appendix A for data sources and description). A consideration particular to Spain is the issue of foreign ownership in the housing market. If the share of foreigner-owned houses is high, then fixing the housing stock to GDP ratio at 400 percent can overstate the importance of housing price transmission mechanism in our model. While the Bank of Spain does not offer the breakdown of housing stock between local residents and foreigners, it reports the share of foreign investment in property as a percentage of GDP, which stands at only one sixteenth of total investment in residential housing. However, since $\gamma$ is an important parameter of the model, below we perform robustness check by setting $\gamma = 0.1$, a level consistent with the U.S. housing market indicators.

We set $v$, the elasticity of output to entrepreneurial real estate, to 0.11. This number implies a

[16] See Bayoumi, Laxton and Pesenti (2004) for details.

plausible 50 percent annual steady-state ratio of commercial real estate to GDP. The depreciation rate for housing $\delta^h$ is set equal to 0.006. This number pins down the ratio of residential investment to total output at around 9 percent, as in the data.

We calibrate investment adjustment cost parameter to match the moments of the model to the data. For the period 1980:Q1-2008:Q4, the ratio of standard deviations of investment to output in the data is 1.81; to replicate this in the model, we set $\psi = 9$.

We set the price and wage stickiness parameters $\omega_p = \omega_w$ to 0.75, which implies that prices and wages are reset on average every four quarters. This value of $\omega_p$ is based on recent empirical research on the degree of price rigidity in the Euro area, which shows that the average duration of a price contract ranges from 4 to 5 quarters.[17] Finally, we normalize the amount of land available to the construction sector to unity: $T = 1$.

Credit constraint parameters are calibrated using Spanish credit market data. During the 2004-2008 period, the loan-to-value (LTV) ratio for an average household was 0.62. We assume that impatient households borrow more than the average amount; therefore, we set $l^m = 0.76$, which implies a 36 percent household credit to GDP ratio, close to 42 percent observed in the data for the 1997-2008 period. Due to lack of data on LTV ratios for entrepreneurs and construction sector, we set $l^e = l^c = 0.27$ to match the implied 52 percent steady state business credit to GDP ratio to the Spanish data.

Finally, we estimate the parameters of the productivity process as follows: $\rho_a = 0.67$ and the standard deviation of the shock $\sigma_\varepsilon^a = 0.005$ (see Appendix C for details).

The coefficients for the monetary policy rule are taken from Díaz-Roldán and Montero-Soler (2004); these are estimated using Spanish data for the period 1989:3 to 1998:4, i.e., after Spain had joined the European Monetary System. We set $\rho_i = 0.63$, $\rho_\pi = 2.30$ and $\rho_y = 0.39$. We estimate the standard deviation of the shock to the interest rate to be $\sigma_\varepsilon^i = 0.006$ during the same period.

# 4 Results

## 4.1 The Role of the Construction Sector

To more clearly demonstrate the importance of construction sector for the dynamics of housing investment and prices, and for easier comparisons with existing literature, Figure 1 contrasts our model with a simplified version where housing supply is fixed (which can alternately be thought of as an infinite lag in the construction sector, $k = \infty$).[18] Our first observation is that, compared to the setup with no construction, allowing housing supply to respond endogenously and contemporaneously ($k = 0$) to demand pressures unsurprisingly works to reduce the volatility of housing prices. A positive shock to technology or a sudden lowering of interest rates increase demand for housing both through the positive wealth effect and, as a result of higher real estate prices, by relaxing borrowing limits of credit-constrained agents (the financial accelerator approach outlined in Bernanke et al. (1999)).

More importantly, when we increase construction sector lags to 4 and then 8 quarters, the responsiveness of residential investment to economic shocks declines, and housing price volatility goes up, in fact above its no-construction scenario level. The mechanism behind this surprising result is most easily understood following a positive technology shock (left column of Figure 1).

[17] See, for example, Dhyne et al. (2006) and Gorter (2005).

[18] More precisely, we eliminate the construction sector from the model, fix the aggregate housing stock $H_t$ for all periods at its steady state level in the full-blown specification, and set $\delta^h = 0$.

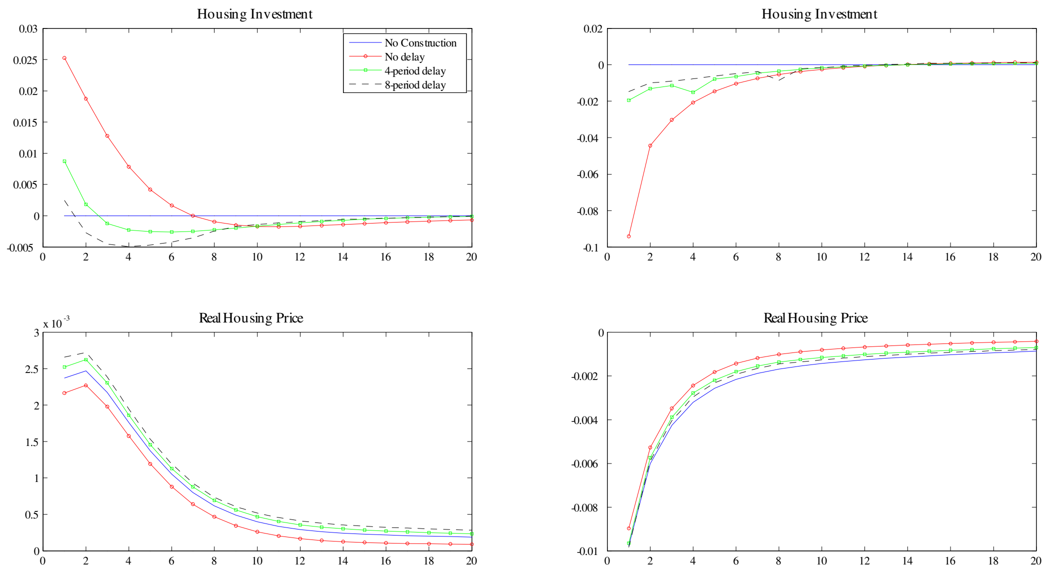


Figure 1: Impulse response functions of housing investment and prices following a shock to productivity (left column) and interest rate (right column): the impact of construction delays.

Higher productivity in the goods production sector drives up the wages of both types of households. Construction sector reduces its investment (vis-à-vis the no-delay scenario) in response to higher labor costs and, more importantly, because it internalizes the fact that demand for housing will be lower than its current level when the new houses finally come up for sale. With 8 period delays, aggregate housing stock actually declines while consumer demand is still above its steady state level; this can be most clearly seen in Figure 2.

These results indicate that in model specifications with non-zero lags in construction higher demand (as a result of positive developments in the economy), coupled with the eventual decline in housing supply, drives up housing prices to a higher level than would be observed if the aggregate stock of housing were permanently fixed, or if the construction sector were able to supply new housing immediately following the shock. This mechanism is going to be of particular importance in explaining why our welfare computations and subsequent prescription for monetary policy regarding housing prices differ significantly from the findings of existing literature.

## 4.2 Performance of the Model

Table 2 compares moments of the data with those of the model for three different construction lags $k = 0, 4, 8$, and for the specification with no construction sector. Before proceeding, we would like to point out that the goal of our paper is to study the importance of construction delays for improving the fit (in particular, of correlations between housing investment, its lags and leads, housing prices and output, none of which can be studied in models without housing construction sector) and

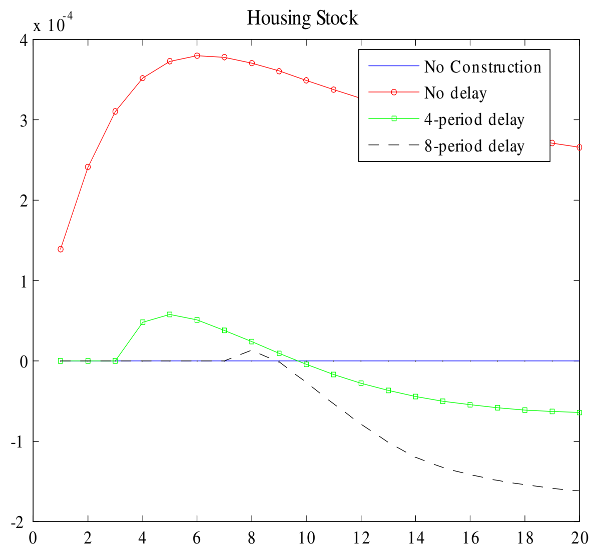


Figure 2: Impulse response functions (following a shock to productivity) of aggregate housing stock for various specifications of construction lag delays.

policy prescriptions of the model, rather than matching all of its business cycle moments to the data. In fact, our model is ill-equipped to match the data perfectly, since it only includes two shocks. Chari, Kehoe and McGrattan (2009) point out that many New Keynesian DSGE models suffer from presence of what the authors call "dubiously structural" shocks, which are not derived from easily interpretable primitives and therefore may give rise to conflicting policy prescriptions. For this reason, we include only the arguably non-controversial and easily measurable shocks: technology and interest rates.

Given the small number of shocks in the model, it nonetheless can capture fairly well many moments of the data, including the cyclicality and patterns of comovement between the key components of aggregate demand. More important, however, is the evidence in support of our main thesis: adding construction delays to the model does improve its fit along several dimensions.

Longer delays in construction decrease the elasticity of housing supply and therefore lead to higher volatility of housing prices. Lower supply responsiveness also causes workers to switch more frequently between the two sectors of the economy: construction and goods production, thus increasing volatility of total hours in construction, $N_c \equiv N_c^p + N_c^m$ (as was discussed above). On the other hand, time-to-build lags do (by construction) perform poorly in matching the relative volatility of housing investment.

The version of the model with $k = 0$ overstates all of the correlations between housing variables and output. By increasing the length of construction lags and thus slowing down the responsiveness of housing investment, we are able to achieve lower correlations between the latter and other key variables of the model: output, housing prices and non-residential investment.

We are also able to study the lead-lag patterns of the housing investment vis-à-vis output. In

| | | Data | $\mathbf{k=0}$ | $\mathbf{k=4}$ | $\mathbf{k=8}$ | $\mathbf{k=\infty}$ |
|---|---|---|---|---|---|---|
| % Standard dev. | $GDP$ | 1.37 | 2.60 | 2.28 | 2.21 | 2.60 |
| (relative to GDP) | $Q$ | 3.67 | 0.48 | 0.61 | 0.66 | 0.58 |
| | $I^h$ | 3.67 | 3.75 | 1.48 | 1.27 | - |
| | $N^c$ | 2.25 | 0.82 | 0.84 | 1.34 | - |
| Correlations | $GDP_t, I_t^h$ | 0.69 | 0.95 | 0.86 | 0.74 | - |
| | $I_t^h, Q_t$ | 0.65 | 0.94 | 0.76 | 0.60 | - |
| | $I_t^h, I_t^k$ | 0.72 | 0.98 | 0.81 | 0.66 | - |
| Lead/Lags | $I_{t-1}^h, GDP_t$ | 0.61 | 0.68 | 0.64 | 0.54 | - |
| | $I_{t+1}^h, GDP_t$ | 0.52 | 0.93 | 0.84 | 0.71 | - |
| | $I_{t-1}^k, GDP_t$ | 0.68 | 0.70 | 0.70 | 0.68 | 0.70 |
| | $I_{t+1}^k, GDP_t$ | 0.58 | 0.98 | 0.96 | 0.95 | 0.96 |

Table 2: Business cycle properties of the model. Numbers in the "Data" column correspond to H-P filtered natural logs of raw data. Column "$\mathbf{k=\infty}$" refers to the version of the model with fixed aggregate housing stock.

the data, the strongest correlation between output and investment is contemporaneous, followed by investment lag and then lead, in that order. In our model, the highest correlation between the two is also contemporaneous, with the best quantitative match occurring for $k = 8$, but residential investment in all specifications is leading the cycle more strongly than it is lagging.

## 4.3 Monetary Policy and Welfare Analysis

We now turn to the question of monetary policy conduct in the presence of such delays. Under the current setup, both the Harmonized Index of Consumer Prices (HICP), tracked by the ECB, and Spanish CPI have a limited coverage of housing prices: they include consumer expenditure on housing services by renters but not by home owners. However, close to 85% of Spaniards are homeowners.[19] Rental prices are much less volatile than average price of housing per square foot (Ayuso and Restoy (2007)); therefore, the central banks effectively do not respond to the developments in the housing markets.

In this paper, we do not analytically derive the optimal monetary policy rule; instead, we engage in the following thought experiment. According to the common macroeconomic wisdom, in a standard New Keynesian DSGE model the consumer welfare maximizing monetary policy targets a weighted average of inflation and output gap.[20] Let us redefine the households' utility function (with $\Theta = 1$) as follows:

$$U_t^j = E_0 \sum_{t=0}^{\infty} \left[\beta^j\right]^t \left\{ \ln \mathbb{C}_t^j - \frac{\left[L_t^j\right]^{1+\chi}}{1+\chi} \right\}, \qquad j \in \{p, m\}$$

with $\mathbb{C}_t^j \equiv C_t^j \left[H_t^j\right]^\gamma$ denoting the housing-consumption bundle. The corresponding price inflation

[19] Diewert (2002), Goodhart and Hofmann (2007).

[20] See, for example, Woodford (2003, Chapter 6).

| | $\mathbf{k=0}$ | $\mathbf{k=4}$ | $\mathbf{k=8}$ | $\mathbf{k=\infty}$ |
|---|---|---|---|---|
| Patient | 0.03 | 0.02 | 0.09 | 0.02 |
| Impatient | 0.01 | 0.03 | 0.12 | 0.03 |
| Entrepreneurs | 0.01 | 0.00 | 0.07 | 0.01 |
| Aggregate | 0.05 | 0.05 | 0.28 | 0.06 |

Table 3: Welfare gains, as a percent of steady state consumption, from increasing $\rho_q$ from 0 to 0.3.

of the bundle evolves over time as follows:

$$\pi_t^{agg} = \pi_t + \rho_q \Delta q_t, \tag{19}$$

where $\rho_q \equiv \frac{\gamma}{\gamma+1}$ and $\Delta q_t$ is the change from last period of the real housing price.

We modify (13) by letting the central bank target this aggregate measure of inflation[21]:

$$\ln(R_t) = (1-\rho_i)\ln\left(\overline{R}\right) + \rho_i \ln(R_{t-1}) + (1-\rho_i)\left[\rho_\pi\left(\pi_t + \rho_q \Delta q_t\right) + \rho_y y^{gap}\right]$$

Finally, we compute welfare gains that result when $\rho_q$ is increased from 0 (the standard Taylor Rule) to 0.3, a value slightly above the one dictated by (19) for $\gamma = 0.25$. The results of our calculations are presented in Table 3.

One of the main findings of our paper is that adding housing prices to the monetary policy function sizably improves welfare of all agents in the model for construction lags greater than zero. When we look at specifications with no lags or with fixed housing supply (the setup considered in most papers on housing prices and monetary policy, which corresponds to columns 2 and 5 in Table 3), our results are consistent with the existing literature - adding housing prices to the Taylor rule does not significantly change agents' welfare. We address the source of this discrepancy after elucidating the mechanism generating welfare gains at long construction lags.

Our calculations suggest that we must consider the differences between credit-constrained and unconstrained agents. To that end, Table 4 shows volatilities of variables that are relevant for welfare calculations of the three agent types.

| | $\mathbf{C}^p$ | $\mathbf{H}^p$ | $\mathbf{C}^m$ | $\mathbf{H}^m$ | $\mathbf{B}^m$ | $\mathbf{C}^e$ | $\mathbf{B}^e$ | $\mathbf{Q}$ |
|---|---|---|---|---|---|---|---|---|
| $\rho_q = 0$ | 0.015 | 0.004 | 0.042 | 0.058 | 0.044 | 0.032 | 0.027 | 0.015 |
| $\rho_q = 0.3$ | 0.013 | 0.004 | 0.039 | 0.052 | 0.040 | 0.029 | 0.024 | 0.013 |

Table 4: Standard deviations of the components of agents' welfare in the 8-period lag setup.

Entrepreneurs derive utility only from consumption; the reduced volatility of housing prices (as the result of more interventionist monetary policy) therefore benefits them only to the extent that it reduces the variance of their borrowing limit. Since entrepreneurs borrow against future value of their housing stock (see equation (9)), more stable housing prices allow them to better smooth their consumption. Same argument applies to credit-constrained households. Additionally, both types of households derive direct utility from their housing stocks, which become more stable

[21] It is worth emphasizing that our model differs from the one considered by Woodford (2003) in a number of ways, in particular due to the presence of credit constraints. Therefore, we do not claim that this expanded policy rule is "optimal" in the sense of being derived from the model equations; we merely use it as a guide in modifying the monetary policy function.

when monetary policy targets housing prices more aggressively. This is due to the fact that the construction sector, which relies heavily on expectation of future economic conditions when making its investment decisions, benefits from more stable and predictable housing prices and is able to better stabilize its housing supply.

Thus, monetary policy that stabilizes housing prices becomes more important to impatient households and entrepreneurs (because of borrowing constraints) and to both types of households (because of housing in the utility) as the responsiveness of housing supply decreases due to longer delays in the construction sector.

The last column of Table 3 shows the welfare gains for the specification with fixed housing stock. The gains are non-linear in the duration of the lag, going back to almost zero if the construction sector is not included at all; this results explains the findings of the existing literature (which either does not model the construction sector, or ignores time-to-build phenomenon) that welfare gains from housing price stabilizations are negligible. What is the cause of this non-linearity?

Section 4.1 and Figure (2) describe the behavior of housing stock following a positive shock to productivity for a range of construction lags. A no-lag construction sector responds to an increase in demand for housing (itself generated by a positive wealth effect) by immediately increasing housing supply. However, when construction lag is increased to 8 periods, housing stock actually falls after experiencing an insignificant increase. This "perverse" response is worse (from the demand-side perspective) than the no-construction scenario; hence, gains from housing price stabilization are larger compared to the fixed housing stock case. Additionally, longer delays in construction add to overall uncertainty in the model, compared to the situation when housing stock is fixed permanently, thus dampening economic activity and generating welfare losses.

## 4.4 Sensitivity Analysis

The two mechanisms that explain our welfare findings depend on having housing in the utility function and on the presence of credit constraints. Below, we perform robustness checks to determine how important is the calibration of the parameters generating these mechanisms for the results of our paper.

Construction sector is particularly important to the Spanish economy; real estate markets in Spain and several other European nations have experienced large fluctuations during the last decade, and so, according to our model, stand to gain from incorporating housing prices into monetary policy. It is possible, however, that the large welfare gains documented in this paper are due to the relatively heavy weight assigned to housing services in consumer utility (governed by the parameter $\gamma$). Therefore, we test the sensitivity of our results by assigning a lower weight to housing services to check whether our policy prescriptions are applicable to other countries as well. We lower $\gamma$ to 0.1, which results in a 170 percent residential housing to GDP ratio, close to the level observed in the U.S.[22] At the same time, we lower $\rho_q$ in the central bank policy rule to 0.1, as dictated by (19). Left panel of Table 5 presents the results of this robustness experiment. As expected, lower weight on housing services leads to smaller welfare gains from housing price stabilization, although the latter are still significant for 8 period construction lag delays.

A high LTV ratio could also increase the size of welfare gains documented in the previous section, since it implies a higher level of credit in the economy and, therefore, a stronger financial accelerator channel and more room for welfare improvements. To check the robustness of our results to the

[22] Iacoviello (2005) sets the weight assigned to housing services in the utility function to 0.1, which fixes the housing stock to GDP ratio at 140 percent, in line with the U.S. data.

| | $\gamma = \mathbf{0.10}$ | | | | $\mathbf{l}^m = \mathbf{0.38}$ | | | |
|---|---|---|---|---|---|---|---|---|
| | $\mathbf{k=0}$ | $\mathbf{k=4}$ | $\mathbf{k=8}$ | $\mathbf{k=\infty}$ | $\mathbf{k=0}$ | $\mathbf{k=4}$ | $\mathbf{k=8}$ | $\mathbf{k=\infty}$ |
| Patient | 0.01 | 0.01 | 0.05 | 0.01 | 0.02 | 0.01 | 0.14 | 0.02 |
| Impatient | 0.00 | 0.01 | 0.05 | 0.01 | 0.01 | 0.02 | 0.12 | 0.02 |
| Entrepreneurs | 0.00 | 0.00 | 0.02 | 0.01 | 0.01 | 0.00 | 0.06 | 0.01 |
| Aggregate | 0.01 | 0.01 | 0.12 | 0.02 | 0.04 | 0.03 | 0.31 | 0.05 |

Table 5: Welfare gains, as a percent of steady state consumption, from $\rho_q$ from 0 to 0.3 for two reparameterizations of the benchmark model.

value of this parameter, we decrease the LTV ratio for impatient households by half; the results of welfare computations are shown in the right panel of Table 5. Qualitatively, the welfare gains in this new scenario are quite similar to those seen in the baseline model: all agent types benefit from the inclusion of housing prices into the monetary policy rule, with the size of the gains increasing in construction lag. Thus, our main findings remain unchanged for economies with less developed financial markets or smaller stocks of real estate relative to GDP.

# 5 Conclusion

We incorporate housing construction sector, characterized by time-to-build delays, into a DSGE model where agents borrow against the value of their real estate holdings. The improvements that arise from this new feature are twofold. First, we show that specifications of the model with delays between commencement and completion of a construction project fit the data (in terms of moments, correlations, and leads/lags of housing investment and prices) much better than a version with no construction sector. Second, we show that, in the presence of such long lags in real estate development, a forward-looking construction sector acts to lower housing supply following a positive productivity shock, which warrants the inclusion of housing prices in the central bank policy rule. The welfare gains from adding housing prices to the Taylor rule are non-negligible for all types of agents; aggregate gains for the entire economy are on the order of 0.3 percent of steady state consumption.

We find that the welfare gains from housing price stabilization are non-linear in the duration of construction lag, decreasing back to zero as the number of lags goes to infinity (models with no housing investment sector can be thought of as limiting cases of extremely long lags in construction). Therefore, recent papers that do not incorporate time delays in housing construction, or that permanently fix housing supply, do not find any noticeable welfare improvements from housing price stabilization by central banks.

There are several ways to refine and extend the results of our paper. Business cycles properties of the model can be improved by a more careful calibration of the various shocks that affect housing market. Differentiating between renters and owners of real estate can yield further insights into the dynamics of housing stock and prices. Construction sector behavior can be made more realistic by endogenizing the duration of time delays. These suggestions offer fertile ground for future research.

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# A Data Sources and Description

Data are taken from Eurostat, ECB, OECD and IMF (IFS) statistics databases.

| | | |
|---|---|---|
| $P_t$ | GDP deflator for Spain. | IFS |
| $Y_t$ | GDP at constant prices, seasonally adjusted | Eurostat |
| $\frac{Q_t}{P_t}$ | Real Spanish housing price | OECD |
| $H_t$ | Stock of residential housing | Banco de España |
| $I_t^k$ | Business fixed investment (non-residential) | Eurostat |
| $I_t^h$ | Residential investment | Eurostat |
| $l^{m,e,c}$ | Loan-to-value ratios | Banco de España |
| $L_t$ | Average hours per employee times the total employment. | OECD |
| $N_c$ | Hours in the construction sector | Eurostat |
| $N_e$ | Hours in the production sector | Eurostat |
| $R_t$ | Spanish overnight interbank rate | OECD |

# B Solution to Model

## B.1 Patient Households FOCs

$$
\begin{aligned}
\frac{1}{R_t} &= \beta^p E_t \left[ \left( \frac{C^p_{t+1}}{C^p_t} \right)^{-\Theta} \frac{1}{\Pi_{t+1}} \right] \\
[L^p_t]^{\chi} &= [C^p_t]^{-\Theta} \frac{W^p_t}{P_t} \\
[C^p_t]^{-\Theta} \frac{Q_t}{P_t} \left\{ 1 + \phi \frac{\Delta H^p_t}{H^p_{t-1}} \right\} &= \gamma \left[ H^p_t \right]^{-\Theta} + \beta^p E_t \left[ C^p_{t+1} \right]^{-\Theta} \frac{Q_{t+1}}{P_{t+1}} \left\{ 1 + \frac{\phi}{2} \left[ \left( \frac{H^p_{t+1}}{H^p_t} \right)^2 - 1 \right] \right\} \\
[C^p_t]^{-\Theta} \left\{ 1 + \psi \left[ \frac{K_t}{K_{t-1}} - 1 \right] \right\} &= \beta^p E_t \left[ C^p_{t+1} \right]^{-\Theta} \left\{ 1 - \delta + \frac{\psi}{2} \left[ \left( \frac{K_{t+1}}{K_t} \right)^2 - 1 \right] + \frac{R_{K,t+1}}{P_{t+1}} \right\}
\end{aligned}
$$

## B.2 Impatient Households FOCs

$$
[C^m_t]^{-\Theta} = \beta^m R_t E_t \left[ \frac{\left[ C^m_{t+1} \right]^{-\Theta}}{\Pi_{t+1}} \right] + \lambda^m_t R_t
$$

$$
[L^m_t]^{\chi} = [C^m_t]^{-\Theta} \frac{W^m_t}{P_t}
$$

$$
[C^m_t]^{-\Theta} \frac{Q_t}{P_t} \left\{ 1 + \phi \frac{\Delta H^m_t}{H^m_{t-1}} \right\} - \lambda^m_t l^m E_t Q_{t+1} =
$$

$$
= \gamma \left[ H^m_t \right]^{-\Theta} + \beta^m E_t \left[ C^m_{t+1} \right]^{-\Theta} \frac{Q_{t+1}}{P_{t+1}} \left\{ 1 + \frac{\phi}{2} \left[ \left( \frac{H^m_{t+1}}{H^m_t} \right)^2 - 1 \right] \right\}
$$

## B.3 Entrepreneurs FOCs

$$
[C^e_t]^{-\Theta} = \beta^e R_t E_t \left[ \frac{\left[ C^e_{t+1} \right]^{-\Theta}}{\Pi_{t+1}} \right] + \lambda^e_t R_t
$$

$$
W^p_t N^p_{e,t} = \alpha (1 - \mu - v) P^e_t Y_t
$$

$$
W^m_t N^m_{e,t} = (1 - \alpha)(1 - \mu - v) P^e_t Y_t
$$

$$
R_{K,t} K_{t-1} = \mu P^e_t Y_t
$$

$$
[C^e_t]^{-\Theta} \frac{Q_t}{P_t} \left\{ 1 + \phi \frac{\Delta H^e_t}{H^e_{t-1}} \right\} - \lambda^e_t l^e E_t Q_{t+1} =
$$

$$
= \beta^e E_t \left[ C^e_{t+1} \right]^{-\Theta} \left( \nu \frac{P^e_{t+1}}{P_{t+1}} \frac{Y_{t+1}}{H^e_t} + \frac{Q_{t+1}}{P_{t+1}} \left\{ 1 + \frac{\phi}{2} \left[ \left( \frac{H^e_{t+1}}{H^e_t} \right)^2 - 1 \right] \right\} \right)
$$

## B.4 Construction Sector FOCs

$$
\begin{aligned}
\lambda_t^c &= \frac{1}{R_t} - \beta^c \\
W_t^p &= \frac{\alpha\left(1-\eta\right)\left(\beta^c\right)^{k-1}}{N_{c,t}^p} I_t^c \left(\Lambda_{t+k-1}^c l^c + \beta^c\right) E_t Q_{t+k} \\
W_t^m &= \frac{\left(1-\alpha\right)\left(1-\eta\right)\left(\beta^c\right)^{k-1}}{N_{c,t}^m} I_t^c \left(\Lambda_{t+k-1}^c l^c + \beta^c\right) E_t Q_{t+k}
\end{aligned}
$$

Here $\beta^c$ is the rate at which the construction sector discounts the future; in order to make the credit constraint binding at all times, we require that $\beta^c$ be sufficiently low relative to the lending interest rate in the Home country.

| | 1990-2008 |
|---|---|
| $\rho_a$ | 0.67 (4.51) |
| $\sigma_\varepsilon^a$ | $5.46 \times 10^{-3}$ |

Table 6: OLS estimate of the productivity process (t-stats in parentheses).

# C Estimation

## C.1 Productivity

We assume that in the short run, Spanish stocks of capital and real estate are fixed; this allows us to approximate total factor productivity (TFP) as $\ln A_t \cong \ln Y_t - (1-\mu-\nu)\ln L_t$. (Details on the variable definitions can be found in Appendix A.) We use 1980:Q1-2008:Q4 data on real output and employment to compute the TFP series, and then estimate AR(1) process of the form

$$\ln A_t = \rho_a \ln A_{t-1} + \varepsilon_t^a,$$

Table 6 presents our estimation results.