Collateral Constraints and Macroeconomic Asymmetries

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The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or of any other person associated with the Federal Reserve System.
1. House Prices and Consumption are positively correlated in US data
2. Their correlation seems to get larger when house prices are low
This Paper

- How much do Housing Boom and Bust cycles contribute to movements in consumption?
  We address this question with a general equilibrium model estimated with Bayesian methods.
  In the model, housing collateral constraints may bind or not, depending on housing wealth, leverage, and the state of the economy.
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- We find that:
  Housing boom of 2001-2006: Collateral constraints became slack; the boom contributed little to consumption.
  Housing collapse of 2006-2010: Tighter collateral constraints explain three quarters of the fall in consumption.
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• We find that:
  Housing boom of 2001-2006: Collateral constraints became slack; the boom contributed little to consumption.
  Housing collapse of 2006-2010: Tighter collateral constraints explain three quarters of the fall in consumption.

• Asymmetry is supported by regressions on state- and MSA-level data
The Basic Idea

- Household maximizes \( U = E_0 \sum_{t=0}^{\infty} \beta^t (\log c_t + j \log h_t) \) subject to

\[
\begin{align*}
  c_t + q_t h_t &= y + b_t - Rb_{t-1} + q_{t+1} h_{t-1} (1 - \delta) \\
  b_t &\leq mq_t h_t \\
  \log q_t &= \rho \log q_{t-1} + v_t, \quad v_t \sim N \left(0, \sigma^2\right)
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\]

- The solution of this problem is a consumption function of the form

\[ c_t = C (q_t, b_{t-1}, h_{t-1}) \]

- Consumption function will have the property that consumption increases with house prices, but at a decreasing rate.
- When \( q \) is low, borrowing constraint binds, and consumption moves in lockstep with \( q \)
  
- When \( q \) is high, borrowing constraint is slack, and consumption is less sensitive to \( q \)
Model’s solution. Consumption function, $C(q, \bar{b}, \bar{h})$
In summary:

1. High house prices are associated with slack borrowing constraints, and with a lower sensitivity of consumption to changes in house prices.

2. When household borrowing is constrained – more likely when house prices are low and initial debt is high – the sensitivity of consumption to changes in house prices becomes large.

These ideas are developed further both in the full model and in the empirical analysis to follow.
The Full Model: Overview

- Standard monetary DSGE model augmented to include a housing collateral constraint along the lines of Kiyotaki and Moore (1997), Iacoviello (2005), and Liu, Wang, and Zha (2013). Allow for the dual role of housing as a durable good and as collateral for “impatient” households.

- To this framework, add two elements that generate important nonlinearities.
  1. Monetary policy may be constrained by the ZLB.
  2. Housing collateral constraint binds only occasionally.

- (Monetary DSGE model: RBC core with price and wage rigidities, habits in consumption, and investment adjustment costs)
The Model: Key equations

Within each group of patient and impatient households, a representative household maximizes:

\[
\begin{align*}
E_0 \sum_{t=0}^{\infty} \beta_t z_t \left( \Gamma \log (c_t - \varepsilon c_{t-1}) + j_t \log h_t - \frac{1}{1+\eta} n_t^{1+\eta} \right), \\
E_0 \sum_{t=0}^{\infty} (\beta')^t z_t \left( \Gamma' \log (c'_t - \varepsilon c'_{t-1}) + j_t \log h'_t - \frac{1}{1+\eta} n'_t^{1+\eta} \right).
\end{align*}
\]

\(z_t\): intertemporal preference shock
\(j_t\): housing preference/demand shock
Households

- Patient households maximize their utility subject to:

\[ c_t + q_t h_t + i_t = \text{resources}_t - b_t, \]

where \( \text{resources}_t \) includes wage, capital income, housing wealth, dividends.

- Impatient households do not accumulate capital. Their maximum borrowing \( b_t \) is given by the value of their home times the LTV ratio \( m = 0.9 \):

\[ c'_t + q_t h'_t = \text{resources'}_t + b_t, \]

\[ b_t \leq \gamma \frac{b_{t-1}}{\pi_t} + (1 - \gamma) \text{mq}_t h'_t \]

where \( \text{resources'}_t \) includes wage and housing wealth.

- Borrowing constraint allows for inertia, measured by \( \gamma \).
Monetary Policy and Supply Side

- Monetary policy follows Taylor rule that responds to annual inflation and GDP in deviation from trend, subject to the zero lower bound (ZLB):

\[ R_t = \max \left[ 1, R_{t-1}^{R} \tilde{\pi}_{a,t} (1-r_R) \tilde{Y}_{t-1} (1-r_R) \frac{\tilde{Y}_{t-1}}{R^{1-r_R} u_{r,t}} \right]. \]

where \( u_{r,t} \) is an iid monetary policy shock.

- The supply side of the model is completed by

\[ Y_t = n_t^{(1-\sigma)(1-\alpha)} n_t^{\sigma(1-\alpha)} k_{t-1}^{\alpha} \]

and price and wage Phillips curves.

- The parameter \( \sigma \) measures the wage share of impatient households and – indirectly – the importance of collateral constraints. With \( \sigma = 0 \), the model is essentially like any other monetary model.
Data and Shocks

• The estimation is based on observations from 1985Q1 to 2011Q4:
  1. total real household consumption,
  2. price (GDP deflator) inflation,
  3. wage inflation (compensation per hour, nonfarm),
  4. real business fixed investment,
  5. real housing prices (Corelogic),
  6. Federal Funds Rate.

• Six shocks – investment-specific shocks, wage markup, price markup, monetary policy, intertemporal preferences, and preferences for housing.
Solution Method

- We solve the model using the Occbin algorithm (see Guerrieri and Iacoviello, forthcoming JME): the algorithm extends a first-order perturbation approach and applies it in a piecewise fashion to handle occasionally binding constraints.

- Depending on whether the zero lower bound binds or not, and depending on whether the collateral constraint binds or not, we identify four regimes.

- The solution method links the first-order approximation of equilibrium conditions describing each regime.

- The dynamics in each regime depend on how long one expects to be in that regime. How long one expects to be in that regime depends on the state vector.

- The advantage of the method is its accuracy and speed. Speed is what allows us to compute the model’s likelihood in seconds.
How the Policy Functions Look Like...
Computing the Likelihood

- The solution of the model takes the form:

\[ X_t = P(X_{t-1}, \epsilon_t)X_{t-1} + D(X_{t-1}, \epsilon_t) + Q(X_{t-1}, \epsilon_t)\epsilon_t \]
Computing the Likelihood

- The solution of the model takes the form:

$$X_t = P(X_{t-1}, \epsilon_t)X_{t-1} + D(X_{t-1}, \epsilon_t) + Q(X_{t-1}, \epsilon_t)\epsilon_t$$

- ... and in terms of observables, through the observation equation $Y_t = H_tX_t$, we have:

$$Y_t = H_tP(X_{t-1}, \epsilon_t)X_{t-1} + H_tD(X_{t-1}, \epsilon_t) + H_tQ(X_{t-1}, \epsilon_t)\epsilon_t$$

We initialize $X_0$, and can recursively solve for $\epsilon_t$, given $X_{t-1}$ and the current realization of $Y_t$. 
Computing the Likelihood

- The solution of the model takes the form:
  \[ X_t = P(X_{t-1}, \epsilon_t)X_{t-1} + D(X_{t-1}, \epsilon_t) + Q(X_{t-1}, \epsilon_t)\epsilon_t \]

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We initialize \( X_0 \), and can recursively solve for \( \epsilon_t \), given \( X_{t-1} \) and the current realization of \( Y_t \).

- Given that \( \epsilon_t \) is \( NID(0, \Sigma) \), a change in variables argument implies that the log likelihood for \( Y \) given parameters can be written as:
  \[
  \log f(Y^T) = -\frac{T}{2} \log(\det(\Sigma)) - \frac{1}{2} \sum_{tt} \epsilon' (\Sigma^{-1}) \epsilon_t - \sum_t \log(|\det(H_tQ_t)|)
  \]
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\]

- We impose standard prior on the parameters and estimate them using random walk Metropolis-Hastings algorithm.
Calibration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m$</td>
<td>Maximum LTV</td>
<td>0.9</td>
</tr>
<tr>
<td>$\eta$</td>
<td>labor disutility</td>
<td>1</td>
</tr>
<tr>
<td>$\beta$</td>
<td>discount factor, patient agents</td>
<td>0.995</td>
</tr>
<tr>
<td>$\bar{\pi}$</td>
<td>steady-state gross inflation rate</td>
<td>1.005</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>capital share in production</td>
<td>0.3</td>
</tr>
<tr>
<td>$\delta$</td>
<td>capital depreciation rate</td>
<td>0.025</td>
</tr>
<tr>
<td>$\bar{j}$</td>
<td>housing weight in utility</td>
<td>0.04</td>
</tr>
<tr>
<td>$X_p, X_w$</td>
<td>average price and wage markup</td>
<td>1.2</td>
</tr>
</tbody>
</table>

We estimate:

- the parameters governing the shocks processes;
- the parameters governing the nominal and real rigidities;
- the parameters governing the monetary policy rule;
- the wage share of impatient households, and their discount rate.
Model Results: Selected Estimated Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Prior type [mean, std]</th>
<th>Posterior Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta'$</td>
<td>discount factor, impatient</td>
<td>normal [0.99, .0015]</td>
<td>0.9895</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>habit in consumption</td>
<td>beta [0.5, 0.1]</td>
<td>0.6399</td>
</tr>
<tr>
<td>$\phi$</td>
<td>investment adjustment cost</td>
<td>gamma [5, 2]</td>
<td>5.0307</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>wage share, impatient</td>
<td>beta [0.5, 0.20]</td>
<td>0.4151</td>
</tr>
<tr>
<td>$r_\pi$</td>
<td>inflation resp. Taylor rule</td>
<td>normal, 1.5, 0.25]</td>
<td>1.7385</td>
</tr>
<tr>
<td>$r_R$</td>
<td>inertia Taylor rule</td>
<td>beta [0.75, 0.1]</td>
<td>0.5200</td>
</tr>
<tr>
<td>$r_Y$</td>
<td>output response Taylor rule</td>
<td>beta [0.125, 0.025]</td>
<td>0.0796</td>
</tr>
<tr>
<td>$\theta_\pi$</td>
<td>Calvo parameter, prices</td>
<td>beta [0.5, 0.075]</td>
<td>0.9190</td>
</tr>
<tr>
<td>$\theta_w$</td>
<td>Calvo parameter, wages</td>
<td>beta [0.5, 0.075]</td>
<td>0.9170</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>inertia borrowing constraint</td>
<td>beta [0.5, 0.1]</td>
<td>0.4547</td>
</tr>
</tbody>
</table>
Model Results: Effect of housing demand shocks

- **House Prices**
  - % from steady state
  - Graph showing the percentage change in house prices over time.

- **Consumption**
  - % from steady state
  - Graph showing the percentage change in consumption over time.

- **Hours Worked**
  - % from steady state
  - Graph showing the percentage change in hours worked over time.

- **Multiplier on Borrowing Constraint level**
  - Graph showing the multiplier effect on borrowing constraint levels over time.

The model results illustrate the impact of housing demand shocks on various economic indicators, including house prices, consumption, hours worked, and the borrowing constraint level.
Specification Checks and Sensitivity Analysis

1. Re-estimate model assuming different initialization scheme
2. Filter shocks assuming true parameters are known
3. Estimate shocks and parameters from data generated by artificial model
4. Use different detrending method
5. Allow for TFP shocks and variable capital utilization
6. Check errors of intertemporal equations and compare policy functions against a much slower version of the model that allows for precautionary behavior stemming from future shocks.
Consumption and the Housing Boom and Bust

- How much did collateral constraints contribute to the decline in consumption?
- By construction, estimated model explains everything in sample. However, it is important to study which shocks and frictions are important in driving the model’s dynamics.
- To understand the importance of collateral constraints, we estimate the restricted model with $\sigma = 0$, and run a horse race between baseline model and model with $\sigma = 0$. 
The estimated simulated multiplier

House Price (% from trend) vs. Model implied multiplier (level)
Consumption and House Prices: Data and Model

(Data, and all shocks)

House Prices (Housing Demand)

Consumption (Housing Demand)
Consumption and House Prices: Data and Model

(Housing Demand Shocks Only)

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House Prices (Housing Demand)

Consumption (Housing Demand)
Consumption and House Prices: Data and Model

(Housing Demand Shocks Only - model w/o frictions)

House Prices (Housing Demand)

Consumption (Housing Demand)
Summary of Comparison

- The baseline model comes close to matching the evolution of both housing and consumption with just the housing shocks,
- By contrast, housing shocks have no bearing on consumption for the model without the collateral constraints.
- Restricted model is completely dependent on a sequence of large consumption shocks to match the consumption data.
- The posterior odds ratio favors the baseline model that does not call for the additional sequence of consumption shocks.
Checks on Solution Algorithm

- We assess the accuracy of the solution method for the full model by computing the errors of the model’s intertemporal equations.
- The errors arise both because of the linearization of the original nonlinear model, and because the method abstracts from precautionary motives due to possibility of future regime switches.
- We focus on the intertemporal errors for the consumption and housing demand equations of patient and impatient agents.
- We compute the errors using standard monomial integration for the expectation terms and simulating the model under the estimated filtered shocks.
- Across these equations, the mean absolute errors – expressed in consumption units – are about $4 \times 10^{-4}$, that is, $4$ for every $10,000$ spent, a level that can be deemed negligible.
An Alternative Solution Method

- The small intertemporal errors indicate that precautionary motives, while potentially important, are, on average, quantitatively small.
- Nonetheless, one may suspect that, in the housing boom that preceded the crisis, agents would have wanted to engage in precautionary saving to insure against bad shocks.
- Similarly during the crisis, uncertainty about the path and duration of the zero lower bound on interest rates would have affected macroeconomic outcomes through precautionary behavior.
- To assess this possibility, we modify our solution algorithm to account for the possibility of future shocks.
- At each point for which the solution is sought, this alternative algorithm augments the state space with sequences of anticipated shocks and corrects current decisions by gauging the difference between the augmented expectations and the original expectations.
A Simple Example

- To understand the modifications, consider a forward-looking equation of the form:

\[ q_t = \max(0, \beta E_t q_{t+1} + \varepsilon_t), \quad \varepsilon_t \sim \text{NIID}(0, \sigma^2). \]

- The perfect foresight solution assumes that the variance of \( \varepsilon_{t+j} \) is zero for \( j > 0 \).

- Under this assumption, \( E_t^{PF} q_{t+1} = 0 \), where \( E_t^{PF} \) denotes the expectation operator under perfect foresight.

- Accordingly, the solution under perfect foresight is \( q_t = \varepsilon_t \) if \( \varepsilon_t \geq 0 \), and \( q_t = 0 \) if \( \varepsilon_t < 0 \) or, more succinctly:

\[ q_t^{PF} = \max(0, \varepsilon_t). \]
An alternative expectation operator

- We modify the solution by extending the expectation operator $E_t$.
- We augment the time-$t$ state space with two anticipated shocks to $\varepsilon_{t+1}$ of equal size, opposite sign and equal probability. When integrating the expectations of $\varepsilon_{t+1}$, this approach is equivalent to considering two integration nodes and weights.
- Under this scheme, the two integration nodes are $\sigma$ and $-\sigma$, each with weight $1/2$.
- Accordingly, the expectation of $q_{t+1}$ can be defined as follows:

$$E_t^{RE1}q_{t+1} = (1/2) \max(0, \sigma) + (1/2) \max(0, -\sigma) = (1/2) \sigma,$$

where $E_t^{RE1}$ denotes the expectation taken assuming knowledge that additional shocks will occur in period $t + 1$. 
Revisiting the Solution

- The solution for \( q_t \) becomes:

\[
q_{t}^{RE1} = \max (0, \beta \sigma / 2 + \varepsilon_t).
\]

- We can proceed in similar fashion to add \( n \)–period ahead anticipated shocks (to \( \varepsilon_{t+1}, \varepsilon_{t+2}, \ldots \varepsilon_{t+n} \)).

- For the full model, we have found that 4-period ahead anticipated shocks yield the largest decline in the errors to the intertemporal equations in the proximity of regime switches.
Solution Checks Under the Modified Solution

- The modified algorithm reduces the errors of the intertemporal equations, particularly in periods when the constraints are close to switching, an occurrence which happens, according to our estimates, with some frequency between 1998 and 2006.
- When the collateral constraint is slack but expected to bind in the future, or vice versa, the consumption Euler errors (expressed in base 10 logs) for the borrower and saver fall from $-2.5$ and $-3.9$ to $-2.9$ and $-4.3$, respectively.
- Despite the smaller intertemporal errors, the modified solution method implies only negligible differences in the model’s business cycle properties.
Evidence from Regional Data

• We use state-level and MSA-level data from 1990 to 2010

Regressions ($y$ is log EMP/CARS/ELE, $hp$ is log house prices)

$$\Delta y_{i,t} = \alpha_i + \gamma_t + \beta_{HI} \mathcal{I}_{i,t} \Delta hp_{i,t-1} + \beta_{LO} (1 - \mathcal{I}_{i,t}) \Delta hp_{i,t-1} + \delta X_{i,t-1} + \varepsilon_{i,t}$$

$I_{i,t} = 1$ if house prices are high, 0 if they are low

high: above state-specific trend
Evidence from Regional Data

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- **States**: employment in services (EMP), **auto sales (CARS)**, electricity usage (ELE)
Evidence from Regional Data

- We use state-level and MSA-level data from 1990 to 2010
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$I_{i,t} = 1$ if house prices are high, 0 if they are low
high: above state-specific trend

- **States**: employment in services (EMP), **auto sales (CARS)**, electricity usage (ELE)
- **MSAs**: employment (EMP) and **auto registrations (CARR)**
US States: Auto Sales and House Prices

<table>
<thead>
<tr>
<th></th>
<th>% Change in Auto Sales ($\Delta autot$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta hp_{t-1}$</td>
<td>0.24***</td>
</tr>
<tr>
<td></td>
<td>(0.03)</td>
</tr>
<tr>
<td>$\Delta hp\text{ high}_{t-1}$</td>
<td>-0.05</td>
</tr>
<tr>
<td></td>
<td>(0.04)</td>
</tr>
<tr>
<td>$\Delta hp\text{ low}_{t-1}$</td>
<td>0.62***</td>
</tr>
<tr>
<td></td>
<td>(0.05)</td>
</tr>
<tr>
<td>$\Delta autot_{t-1}$</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>(0.17)</td>
</tr>
<tr>
<td>$\Delta income_{t-1}$</td>
<td>0.34***</td>
</tr>
<tr>
<td></td>
<td>(0.11)</td>
</tr>
</tbody>
</table>

Time effects  no    no    yes    yes    yes
Observations  969   969   969   918   918
R-squared     0.02  0.06  0.86  0.87  0.88
**Instrumenting House Prices, MSA**

We instrument housing price using housing supply elasticity at the MSA level (data from Albert Saiz), as in Mian and Sufi (2011).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Elasticity</th>
<th>El. Delta</th>
<th>Method</th>
<th>Observations</th>
<th>R-squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002-2006 (Boom)</td>
<td>-7.26***</td>
<td>0.24***</td>
<td>OLS</td>
<td>254</td>
<td>0.22</td>
</tr>
<tr>
<td>2006-2010 (Bust)</td>
<td>4.69***</td>
<td>0.49***</td>
<td>IV</td>
<td>254</td>
<td>0.35</td>
</tr>
</tbody>
</table>
# Summary of the Empirical Evidence

Average elasticities measured from the various regressions

<table>
<thead>
<tr>
<th></th>
<th>State</th>
<th>MSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta empl$</td>
<td>$\Delta auto$</td>
<td>$\Delta elec$</td>
</tr>
<tr>
<td>$\Delta hp_{high}$</td>
<td>0.02</td>
<td>0.07</td>
</tr>
<tr>
<td>$\Delta hp_{low}$</td>
<td>0.07</td>
<td>0.20</td>
</tr>
</tbody>
</table>

1. Average sensitivity of demand to changes in house prices around 0.10
2. Conditioning for low and high prices, sensitivity is around 0.06 when house prices are high, 0.14 for negative changes
3. MSA elasticities after instrumenting house prices and focusing on 2002-2010 period even larger
Conclusions

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• Estimated model shows that, as collateral constraints became slack during the housing boom of 2001-2006, expanding housing wealth made little contribution to consumption growth. By contrast, the subsequent housing collapse tightened collateral constraints and sharply exacerbated the recession of 2008-2009.
An application to mortgage relief

• Consider a simple proposal such as mortgage relief for debtors

• The marginal effects of mortgage relief depend drastically on whether house prices are high (and few people are constrained) or low (and many people are constrained)

• With low house prices, debt relief can have substantial expansionary effects.
Two transfers from saver to borrower under different house price scenarios

- Housing Prices
- Transfer
- Consumption
- Hours
- Consumption saver/patient
- Consumption borrower/impatient
Local linearity of $Q$

The graph shows the local linearity of $Q$ with respect to $u_{j,t}$. The top graph illustrates the relationship between $\phi$ and $u_{j,t}$, where $\phi$ increases linearly with $u_{j,t}$ over the range from -0.1 to 0.8. The bottom graph depicts the number of periods where the constraint is expected to be slack, with the constraint becoming slack starting from period 1 and continuing through periods 2 to 13.
Deleveraging in SCF

Mean Value of Mortgages for Families with Positive Mortgages, by Liquidity

- Illiquid Households
- Liquid Households
- Average

Illiquid: Liq/Income<2/12. Liq=CA+SA+Call+MMA+Stock+Bond+max(0,0.7*Home-Mortg)
Deleveraging in Aggregate Data and the Model

Leverage (Total Household Debt over Owner-Occupied Real Estate)