Financial Innovation, the Discovery of Risk, and the U.S. Credit Crisis

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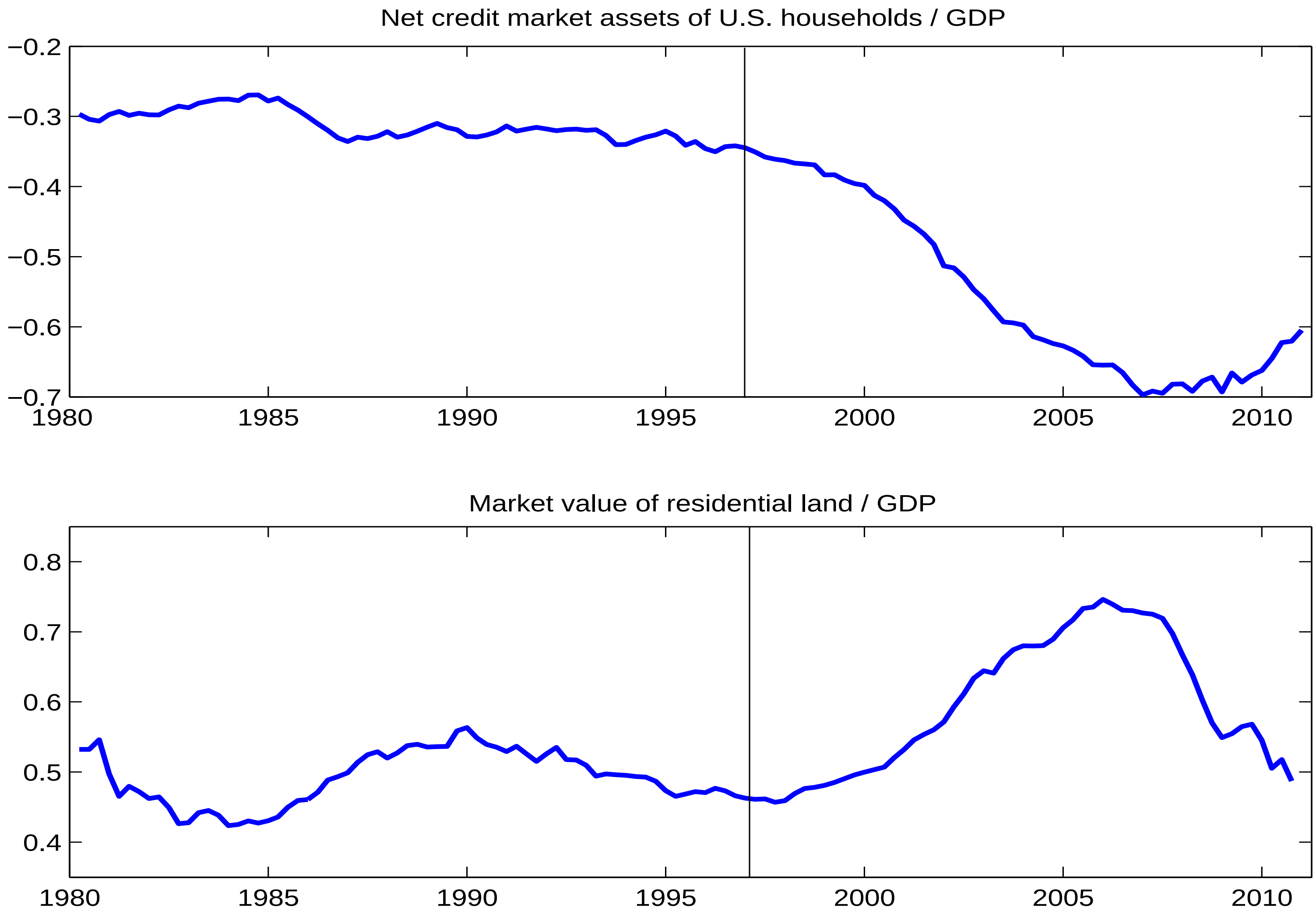
“Booms become busts because justifiable confidence becomes foolish optimism”

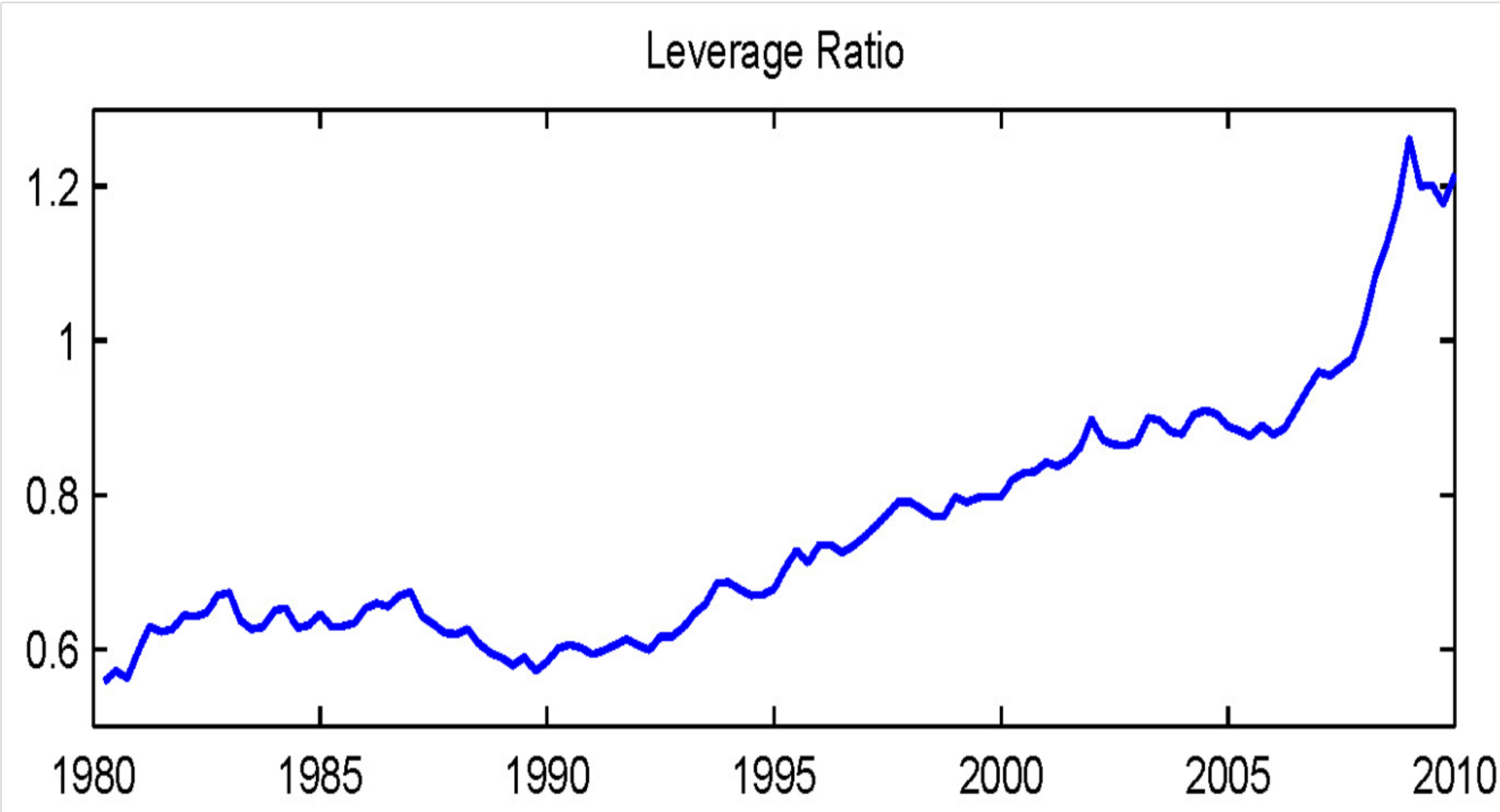
(R. J. Samuelson, “Causes of the Crisis,” Washington Post, 03/19/12).

Motivation

- Rapid rise in household debt, land values and leverage preceded the U.S. credit crisis.
- These trends were associated with financial innovation:
  - New products (CDOs, CMOs, MBSs, CDSs)
  - New laws that removed Glass-Steagall barriers
  - No data on default and performance
  - Belief that assets were risk free ("layering of risk")
- Empirical evidence on credit booms and financial innovation
  - Mendoza & Terrones (2008): 1/3 of credit booms occurred after significant financial reforms
  - U.S. Great Depression, EU Accessions, Baltic states

Net Credit Assets & Residential Land Values





Leverage Ratio
1.2
1
0.8
0.6
1980
1985
1990
1995
2000
2005
2010

Financial Innovation Timeline

- **2010** Dodd-Frank Wall St. Reform Act
- **2008** Net credit assets-GDP bottoms
- **2006** Peak of stock & housing markets
- **2005** CDSs on MBS
- **2000** Com. Fut. Modernization Act
- **1999** Gramm-Leach-Bliley Act
- **1997** First CDS
- **1996** Net credit assets start ⇓
- **1995** New Community Reinvest. Act
- **1987** First CDO

Main Question

Can financial innovation in an environment with imperfect information and credit frictions explain the credit and land price boom/crash observed in the data?

Our story

- Agents face a collateral constraint that limits debt not to exceed a fraction κ of the value of their land holdings.
- Financial innovation introduces two regimes: $\kappa^l < \kappa^h$.
- Agents know κ^h & κ^l but not the regime-switching probabilities. They learn by observing regime realizations, and in the long-run beliefs converge to true probs.
- Overborrowing and overpricing followed by sharp reversals occur because learning leads to optimism and pessimism.
- Learning dynamics interact with Fisherian deflation and produce strong amplification effects.

Main Findings

- After short spell of κ^h agents turn optimistic and believe κ^h is "almost absorbent."
- "Optimistic phase" accounts for:
  - 63 % of the increase in borrowing,
  - 44 % of the increase in residential land value.
- In our calibration, over-borrowing of this magnitude occurs with **24 %** probability!
- Informational friction offsets prec. savings incentives that lower prob. of financial crises in RE models.
- First κ^l starts "pessimistic phase," triggers credit crunch, land price collapse amplified by Fisherian deflation.
- Strong interaction between learning and deflation

Model Economy

- Agents choose consumption, land, bond holdings to max.:

$$E_0^s \left[\sum_{t=0}^{\infty} \beta^t \frac{c_t^{1-\sigma}}{1-\sigma} \right]$$

s.t.:

$$c_t = z_t g(l_t) + q_t l_t - q_t l_{t+1} - \frac{b_{t+1}}{R} + b_t.$$

$$\frac{b_{t+1}}{R} \geq -\kappa_t q_t l_{t+1}$$

- Land is in fixed unit aggregate supply.
- E_0^s is based on agents' beliefs.

Asset Pricing Conditions

- Excess returns:

$$E_t^s\left[R_{t+1}^q - R\right] = \frac{(1-\kappa_t)\mu_t - cov_t^s(\lambda_{t+1}, R_{t+1}^q)}{E_t^s\left[\lambda_{t+1}\right]}$$

$$R_{t+1}^q \equiv \frac{z_{t+1}g'(1) + q_{t+1}}{q_t}$$

- Forward solution for land prices:

$$q_t = E_t^s\left[\sum_{j=0}^{\infty}\left(\prod_{i=0}^{j}\left(\frac{1}{E_t^s[R_{t+1+i}^q]}\right)\right) z_{t+1+j}g'(1)\right]$$

Financial Environment w/ Imperfect Information

- κ_t follows "true" Markov process $F^a = p^a(\kappa_{t+1}|\kappa_t)$.
  - E$[\kappa]$ increases, but so does $\sigma^2(\kappa)$
- Agents do not know F^a, and form Bayesian beliefs $F^s = p_t^s(\kappa_{t+1}|\kappa_t)$, which evolve over time.
- Given two-state Markov process for κ, agents only need to learn about F_{hh}, F_{ll}.
- Passive learning from and about exogenous variables
- Agents are anticipated utility (AU) maximizers.
- Two stage solution: (1) Learning dynamics, (2) Recursive AU optimization problems.

Fisherian feedback if constraint binds

Optimism and κ^h: lower land premia, higher land prices

$$E_t[F^s_{hh}] > F^a_{hh}$$

$$E^s_t[R^q_{t+1}|\kappa_t = \kappa^h, \mu_t > 0] < E^a_t[R^q_{t+1}|\kappa_t = \kappa^h, \mu_t > 0]$$

Pessimism and κ^l : higher land premia, lower land prices

$$E_t[F^s_{ll}] > F^a_{ll}$$

$$E^s_t[R^q_{t+1}|\kappa_t = \kappa^l, \mu_t > 0] > E^a_t[R^q_{t+1}|\kappa_t = \kappa^l, \mu_t > 0]$$

First Stage: Learning Dynamics (Cogley-Sargent, 2008)

- Take as given a history $\kappa^T = (\kappa_T, \kappa_{T-1}, ..., \kappa_1)$ and priors $p(F^s)$ for date $t = 0$.
- Solve for sequence of posteriors $\{f(F^s|\kappa^t)\}_{t=1}^T$
- At every date t, the information set includes κ^t and the values that κ can take.
- Agents form Bayesian posteriors using beta-binomial densities that vary with observed-regime counters
- This is not a signal extraction problem!

Learning Dynamics

- Date-0 Priors: $p(F^s_{ii}) \propto (F^s_{ii})^{n_0^{ii}-1}(1-F^s_{ii})^{n_0^{ij}-1}$
- n_0^{ij}: no. of transitions from i to j assumed to have been observed before date 1
- Posterior density: $f(F^s|\kappa^t) = k(F^s|\kappa^t)/M(\kappa^t)$ where k is the posterior kernel and M is a normalizing constant.
- Updating counters:

$$n^{ij}_{t+1} = \begin{cases} n^{ij}_t + 1 & \text{if } \kappa_{t+1} = \kappa^j \text{ and } \kappa_t = \kappa^i, \\ n^{ij}_t & \text{otherwise.} \end{cases}$$

Learning Dynamics

- Posteriors: $F^s_{hh} \propto Beta(n_t^{hh}, n_t^{hl})$ and $F^s_{ll} \propto Beta(n_t^{lh}, n_t^{ll})$
- Posterior means:

$$E_t[F^s_{hh}] = \frac{n_t^{hh}}{n_t^{hh} + n_t^{hl}}$$

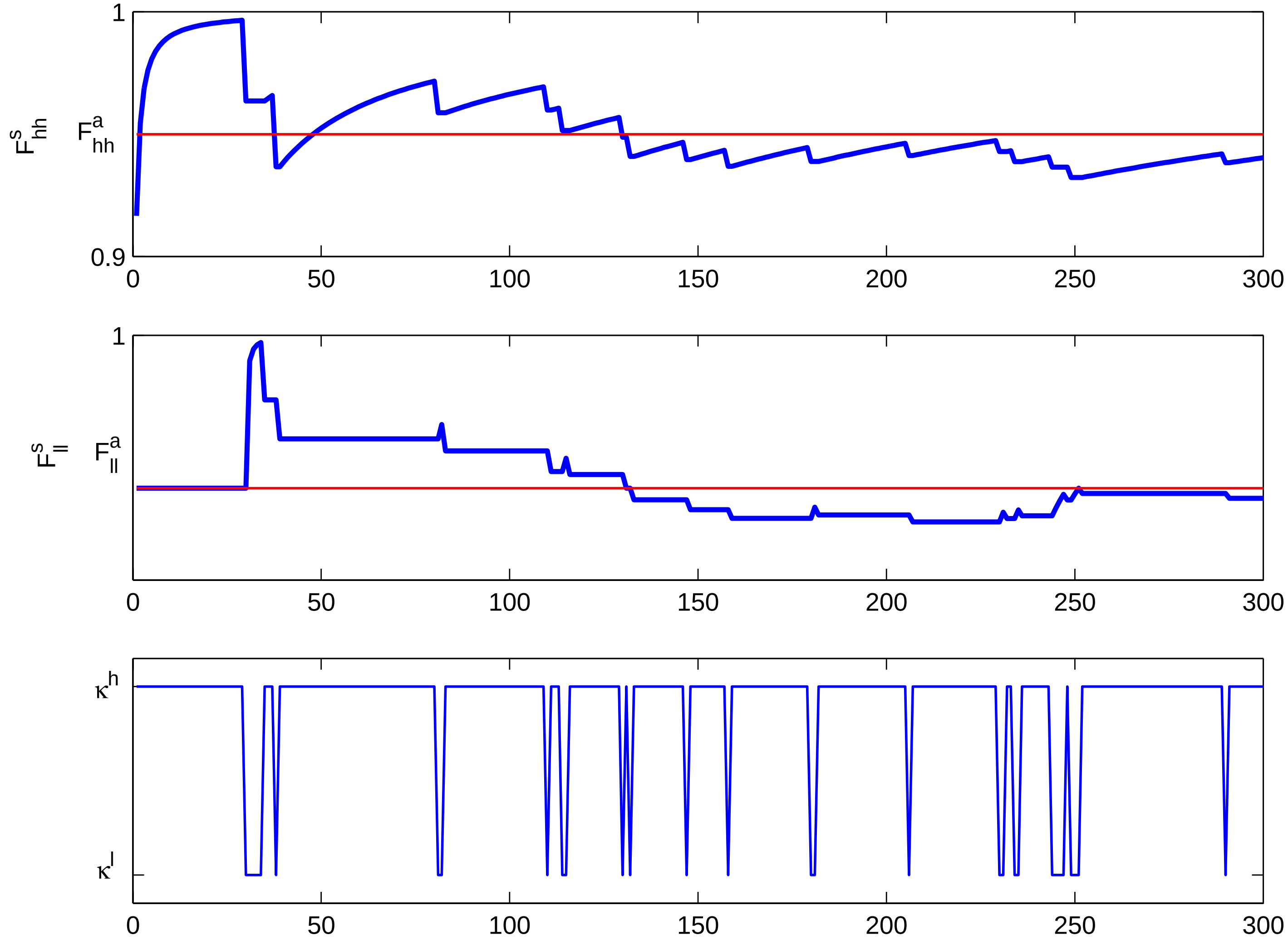
$$E_t[F^s_{ll}] = \frac{n_t^{ll}}{n_t^{ll} + n_t^{lh}}$$

- Posteriors and their means for each regime are updated only when that regime is observed.

Evolution of Beliefs: Illustrative Example

- Assume hypothetical Markov process:
  - $F^a_{hh} = 0.95$, $F^a_{ll} = 0.5$ and generate a 300-period simulation
  - Priors: $p(F^s_{hh}) \sim Beta(0.1, 0.1)$, $p(F^s_{ll}) \sim Beta(0.1, 0.1)$
- Financial innovations, when "untested," can lead to significant underestimation of risk.
  - The initial sequence of realizations of κ^h observed until just before the first κ^l ("optimistic phase") generates substantial optimism.
  - Pessimistic phase after the first κ^l is observed.

Evolution of Beliefs: Illustrative Example



Second Stage: Date-t Anticipated Utility Opt. Problem (AUOP)

- Grab $E_t[F^s_{hh}]$, $E_t[F^s_{ll}]$ calculated in first stage
- At each date t agents solve a full recursive dynamic optimization problem conditional on their date-t beliefs
- Learning process preserves the law of iterated expectations.
- State vector to simplify recursive form: $\eta \equiv (b, z, \kappa)$
- In each AUOP agents take as given a land pricing function $q_t(\eta)$ and solve for a policy function $b'_t(\eta)$.
  - $q_t(\eta)$ introduces credit externality.
  - Iterate to convergence on equilibrium $q_t(\eta)$.

AUOP Recursive Equilibrium Conditions

$$u'(c_t(\eta)) = \beta R \left[\sum_{z' \in Z} \sum_{\kappa' \in \{\kappa^h, \kappa^l\}} E_t^s[\kappa'|\kappa] \pi(z'|z) u'(c_t(\eta')) \right] + \mu_t(\eta)$$

$$q_t(\eta)(u'\left(c_t(\eta)\right) - \mu_t(\eta)\kappa) =$$

$$\beta \left[\sum_{z' \in Z} \sum_{\kappa' \in \{\kappa^h, \kappa^l\}} E_t^s[\kappa'|\kappa] \pi(z'|z) u'(c_t(\eta')) \left(z' g'(1) + q_t(\eta')\right) \right]$$

$$c_t(\eta) = zg(1) - \frac{b_t'(\eta)}{R} + b$$

$$\frac{b_t'(\eta)}{R} \geq -\kappa q_t(\eta) 1$$

$$\text{where} \quad E_t^s[\kappa'|\kappa] \equiv \begin{bmatrix} E_t[F_{hh}^s] & 1 - E_t[F_{hh}^s] \\ 1 - E_t[F_{ll}^s] & E_t[F_{ll}^s] \end{bmatrix}.$$

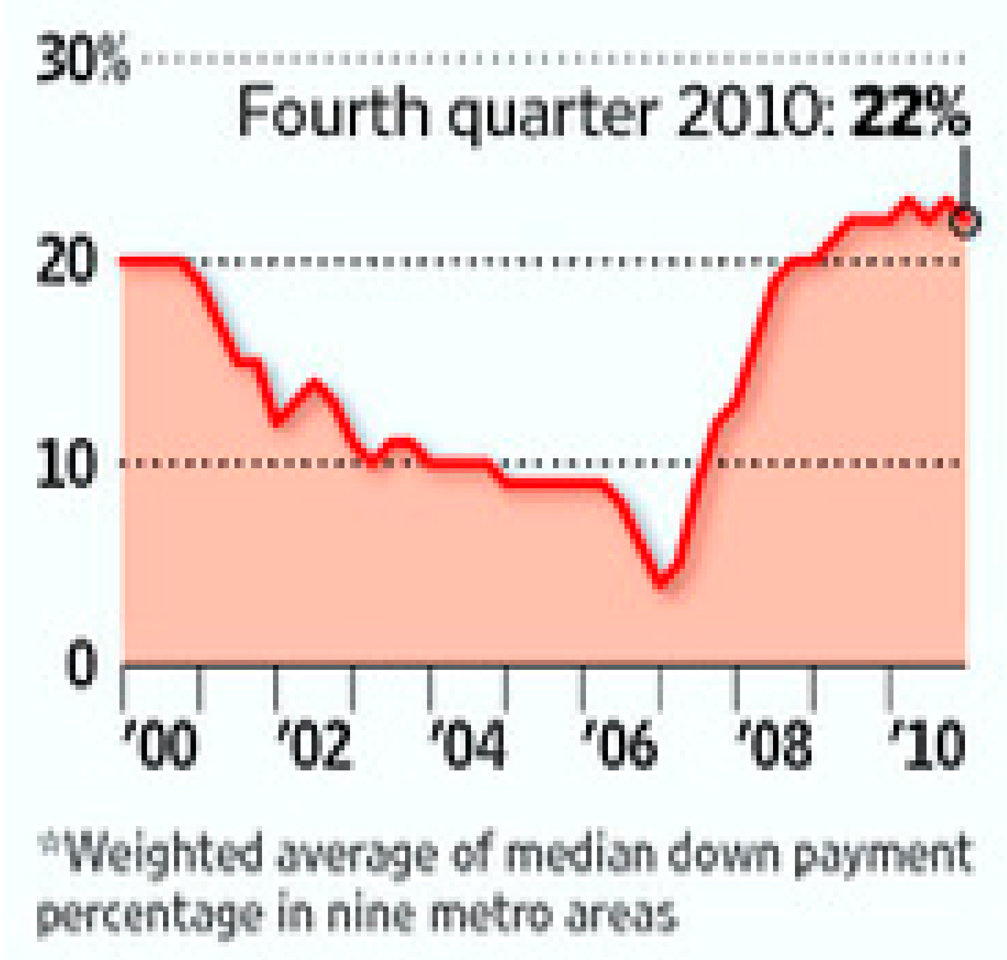
Quantitative Analysis: Financial Innovation Experiment

- Pre-financial innovation: Before 1997, regime with constant κ^l but stochastic TFP
- Financial Innovation: 1997Q1, introduction of regime with two possible values of κ and first realization of κ^h
  - First publicly available securitization of CRA loans.
  - Net credit assets-GDP ratio started to fall in 1997.
- Financial crisis: 2007Q1, first realization of κ^l. Early stages of the subprime mortgage crisis in Fall 2006.
- Learning period of $T =$48 quarters, first 40 with κ^h and remaining 8 with κ^l.
  - 24% probability using calibrated "true process" for κ

Calibration of Leverage Limits

- Macro estimate of household leverage ratio: net credit market assets relative to value of residential land.
- Set κ^l by combining the 1980Q1-1996Q4 average leverage ratio, calibrated R and collateral constraint: $\kappa^l = 0.659/1.0266 = 0.642$.
- κ^h is set to the 2006Q4 leverage ratio: $\kappa^h = 0.926$.

Median Down Payments in Large Cities



Calibration of Learning Process

- Assume common, symmetric date-0 priors: $F^s_{hh}{=}F^s_{ll}$, $n_0^{ii} = n_0^{ij} = n_0$
- Set n_0 such that the model matches excess return on land relative to risk free rate for 1997Q2
  - Proxied with 1997Q2 spread on Fannie Mae RMBS with 30-year maturity (48 basis pts.)
  - Yields $n_0 = 0.0205$
- Using $n_0^{ii} = n_0^{ij} = 1$, i.e. $U(0,1)$, implies having observed 4 transitions (undesirable for modeling innovation!)
  - Same mean prior (0.5) but 1/3 the variance (0.083 v. 0.240).
- $n_0^{ii} = n_0^{ij} = 0$ would be most natural.

Calibration of "True" Regime-Switching Probabilities

- Solving the AUOPs does not require knowing F^a.
- Calibrating F^a is useful for evaluating the impact of the informational friction by comparing against RE.
- $F^a_{hh} = 0.964$ so that mean duration of κ^h regime is 7 years based on Mendoza and Terrones (2008).
  - Conditional on observing κ^h at date 1, the probability of observing κ^h the following 39 periods is 0.241.
- Assume symmetric process, so $F^a_{ll} = 0.964$

Calibration of "Standard" Parameters

- $r = 2.66\%$ annually is the average ex-post real interest rate on three-month U.S. T-bills during 1980Q1-1996Q4.
- Set β so that the pre-financial-innovation model matches the observed std. dev. of consumption relative to output.
  - This yields $\beta = 0.91$ ($\beta R = 0.934 < 1$).
  - Prec. savings & consumption tilting produce ergodicity.
- Using pre-97 ql/y, R, and condition that arbitrages the returns on land and bonds: $\alpha = (ql/zl^{\alpha})[R - 1 + \beta^{-1}(1 - \beta R)(1 - \kappa^{l})] = 0.0251.$
- Markov process for z approximates an AR(1) process ($\ln(z_t) = \rho \ln(z_{t-1}) + e_t$) fitted to U.S. HP-filtered GDP.

Calibration Parameters

β	Discount factor (annualized)	0.91
σ	Risk aversion coefficient	2.0
c	Consumption GDP ratio	0.673
A	Lump-sum absorption	0.321
r	Interest rate (annualized)	2.660
ρ	Persistence of endowment shocks	0.869
σ_e	Standard deviation of TFP shocks	0.008
α	Factor share of land in production	0.025
l	Supply of land	1.0
κ^h	Value of κ in the high securitization regime	0.926
κ^l	Value of κ in the low securitization regime	0.642
F^a_{hh}	True persistence of κ^h	0.964
F^a_{ll}	True persistence of κ^l	0.964
n_0^{hh}, n_0^{hl}	Priors	0.0205

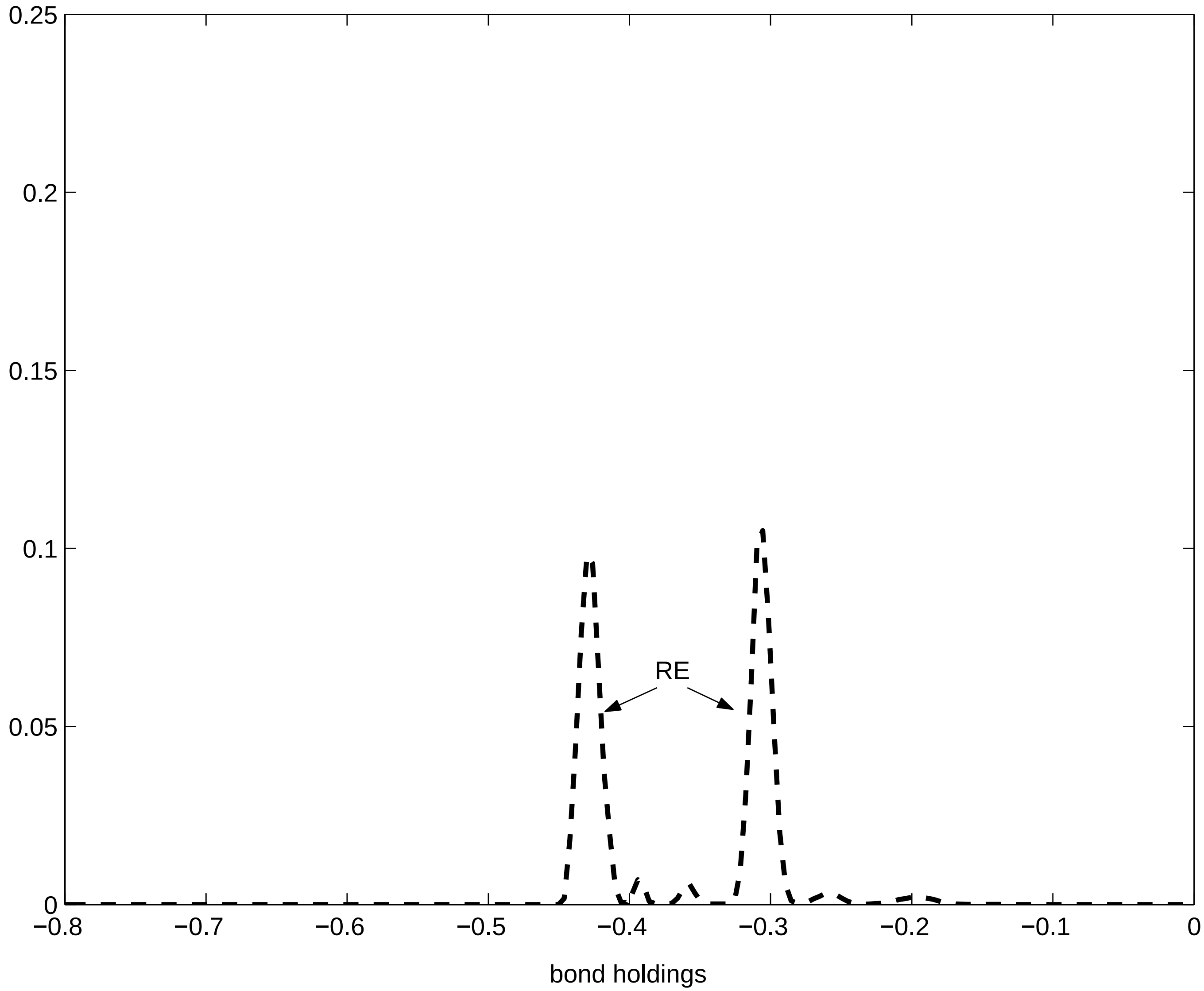
Quantitative Analysis

- "True" v. "Conjectured" long-run distributions
- Forecast functions of equilibrium dynamics conditional on κ^T and $\{f(F^s|\kappa^t)\}_{t=1}^T$
- Turning points (changes at peak of optimism and at financial crisis)
- Projected excess returns at the turning points
- Sensitivity analysis
- Three scenarios: Baseline, RE and FVL (without Fisherian deflation, using $\frac{b_{t+1}}{R} \geq -\kappa_t \bar{q} l_{t+1}$).

Main Findings

- Substantial over-borrowing in long-run distributions.
- Forecast functions: in optimistic phase agents borrow more in the learning model than in RE or FVL.
- As agents overborrow during the optimistic phase, they also bid more aggressively for the risky asset $\longrightarrow$ price of land $\uparrow$
- Switch to the pessimistic phase in period 41 brings large corrections in bond holdings, land price, consumption.
- Excess returns: during the optimistic phase agents are willing to hold risky land at lower excess returns than RE.
  - This is reversed during the pessimistic phase.

Long-run Distributions of Bond Holdings



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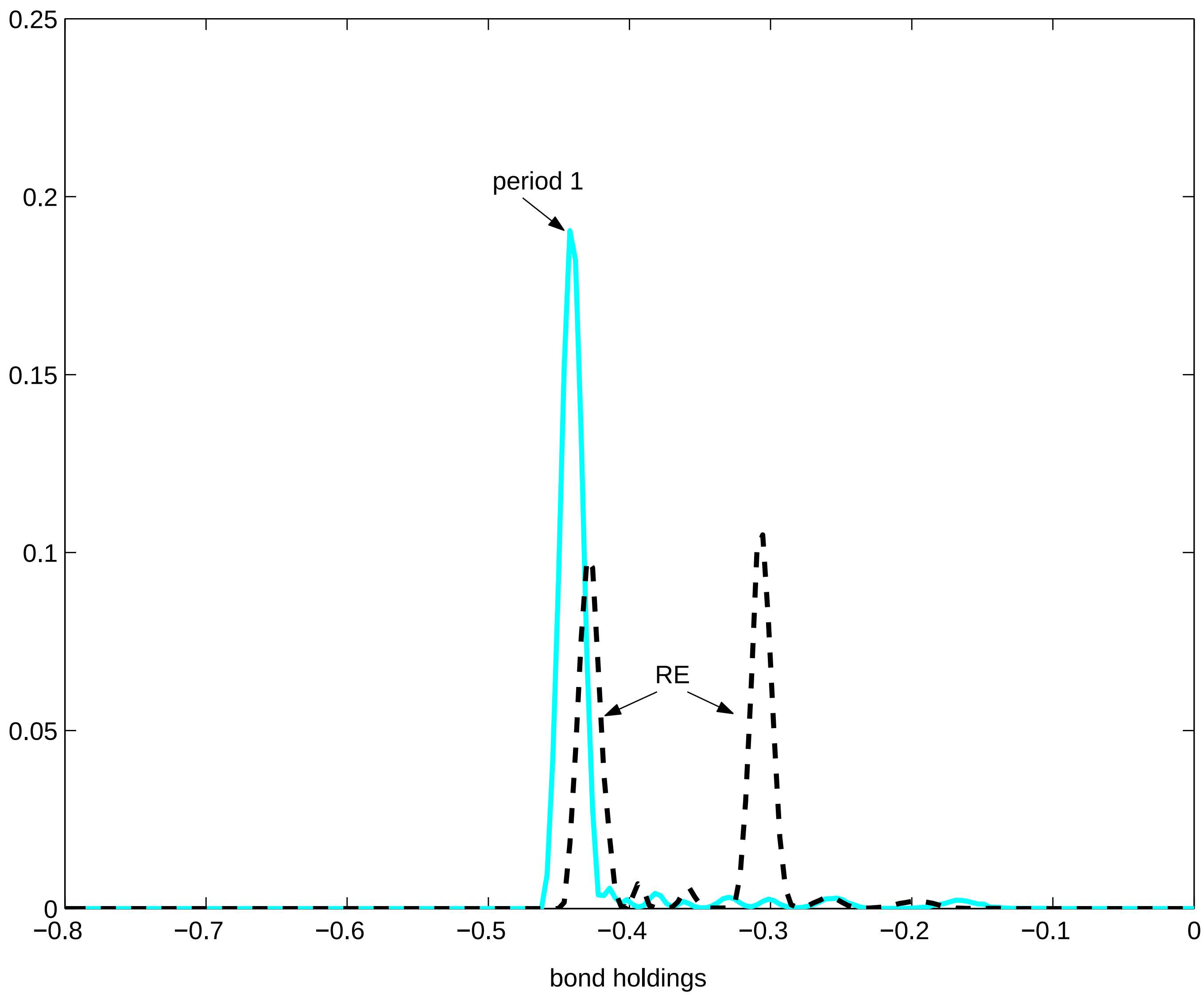

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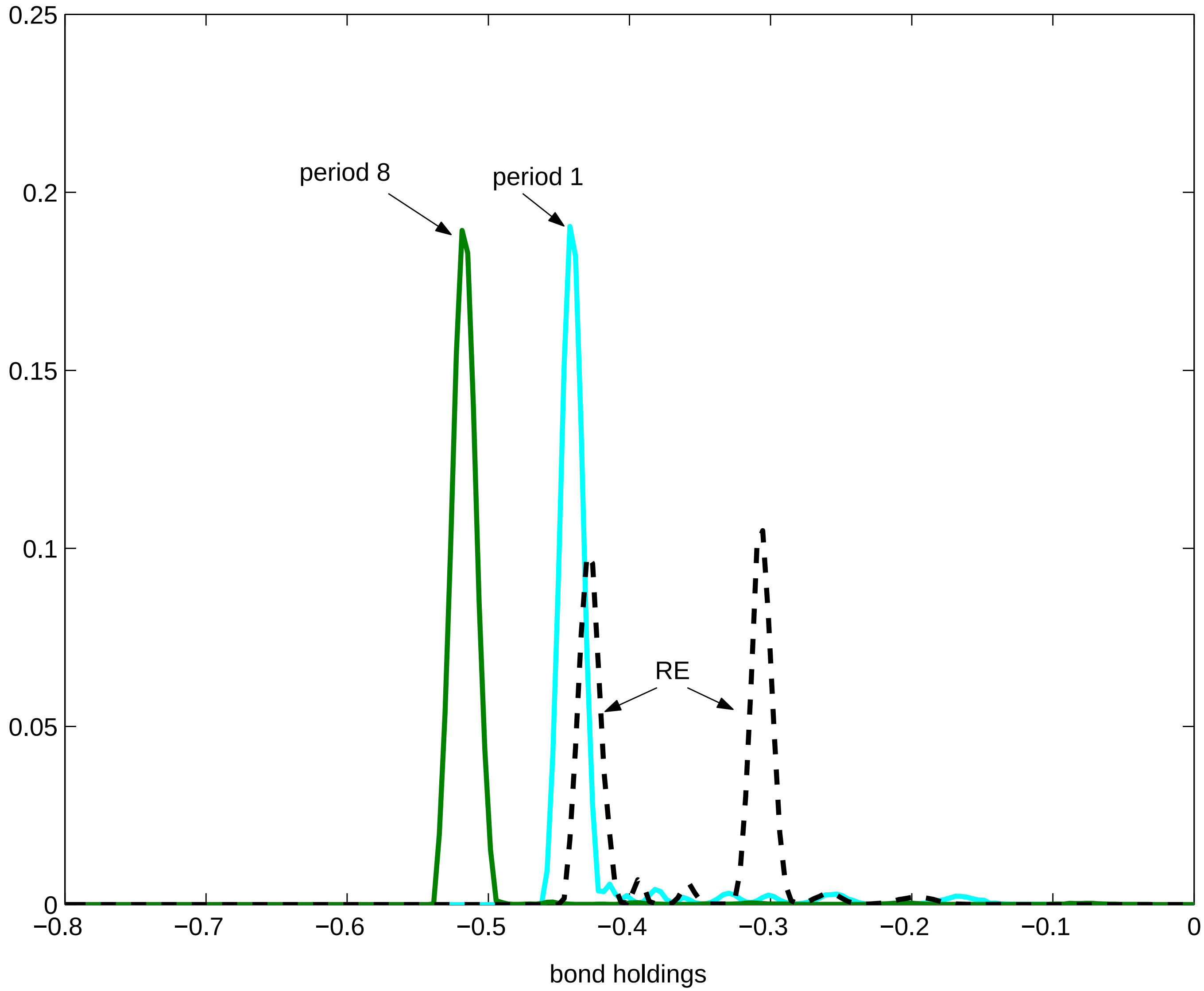

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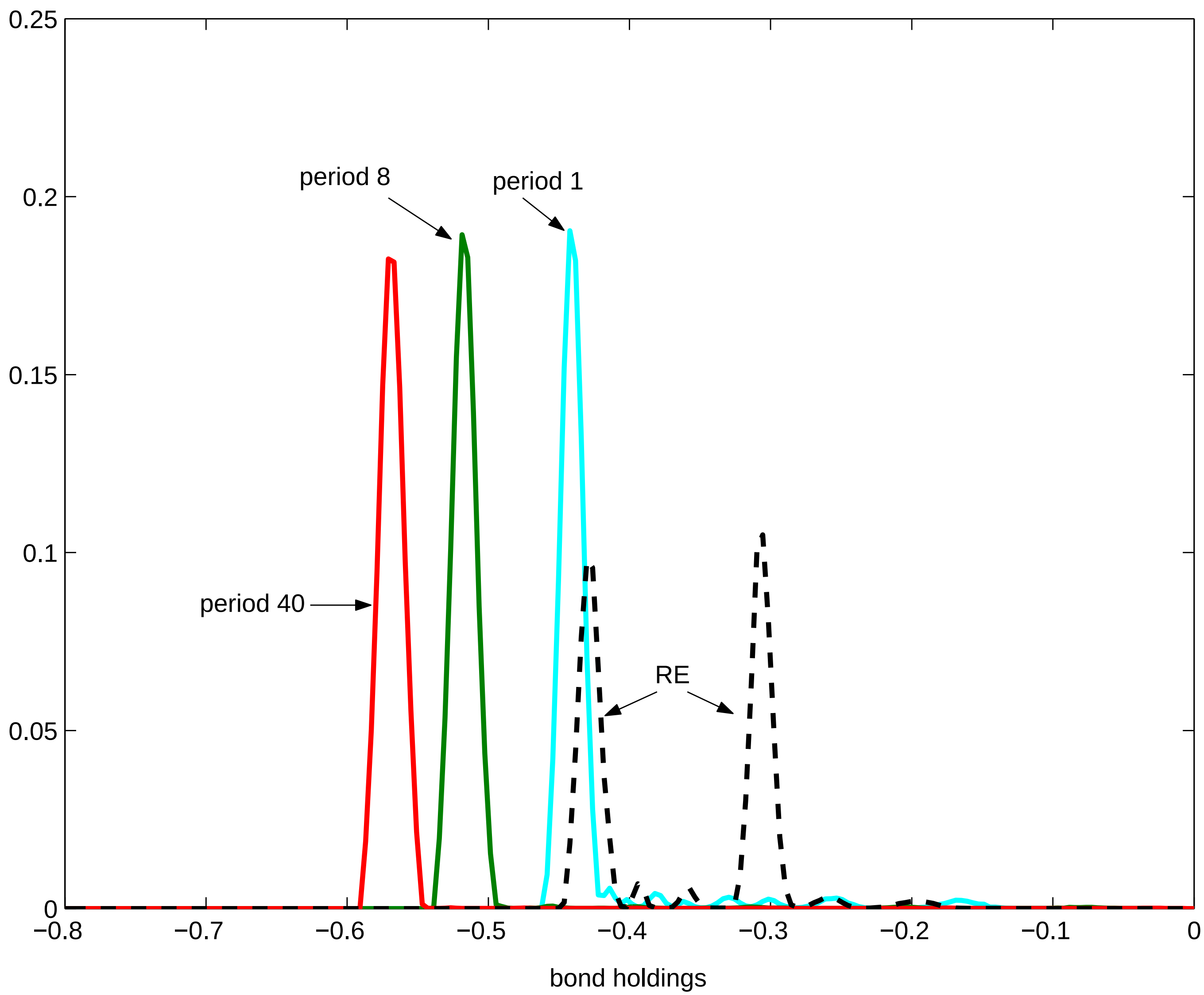

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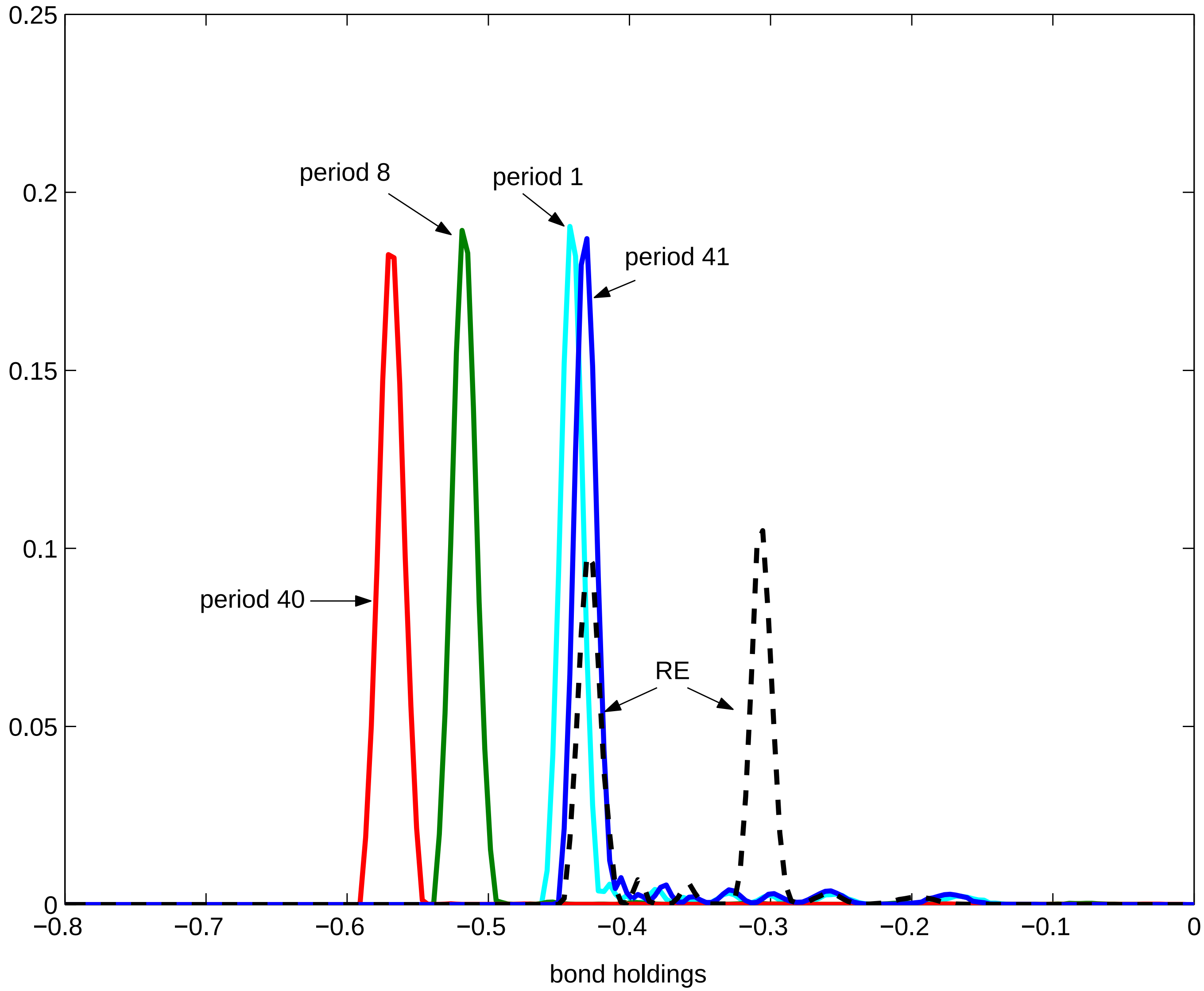

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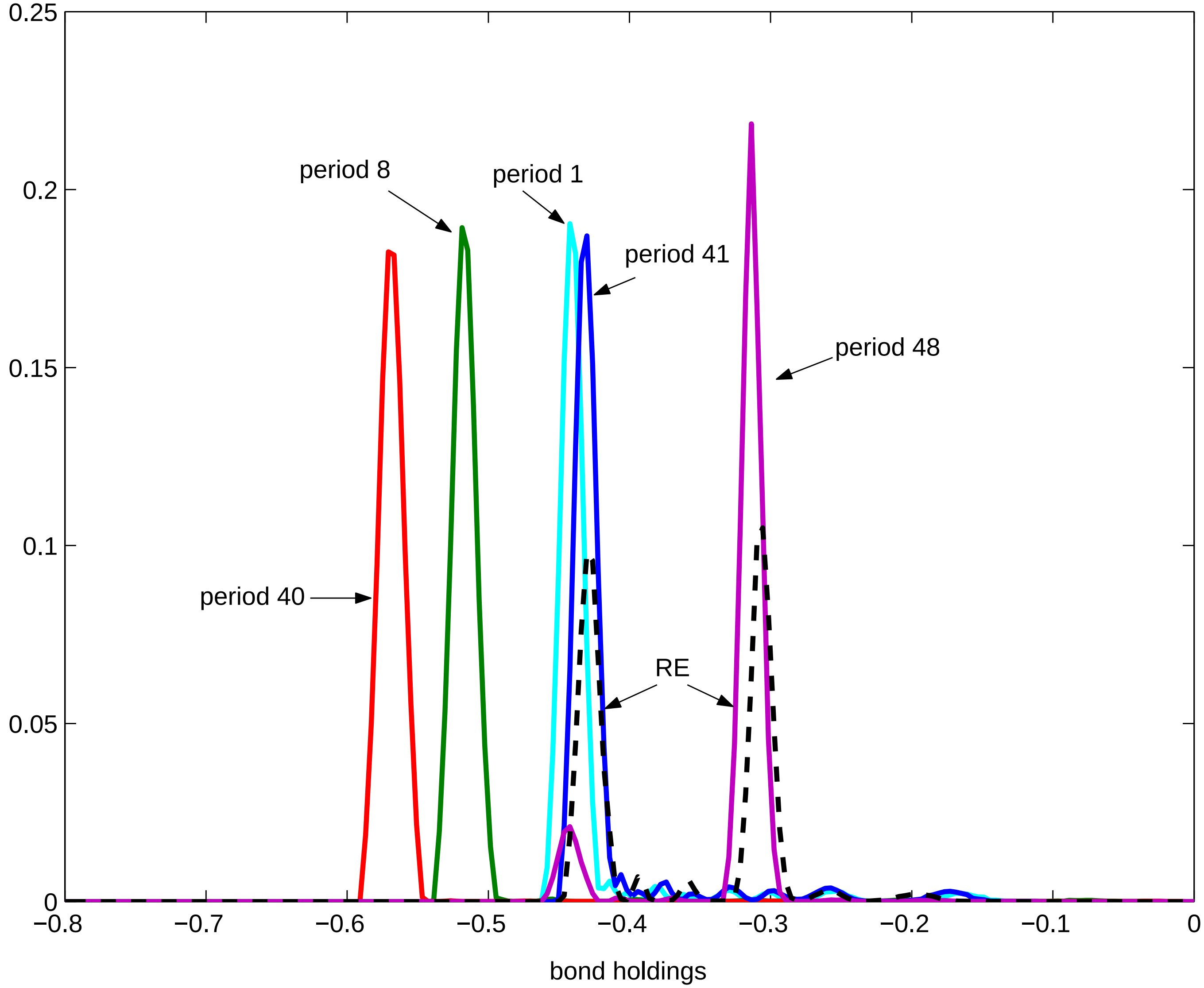


Forecast Functions

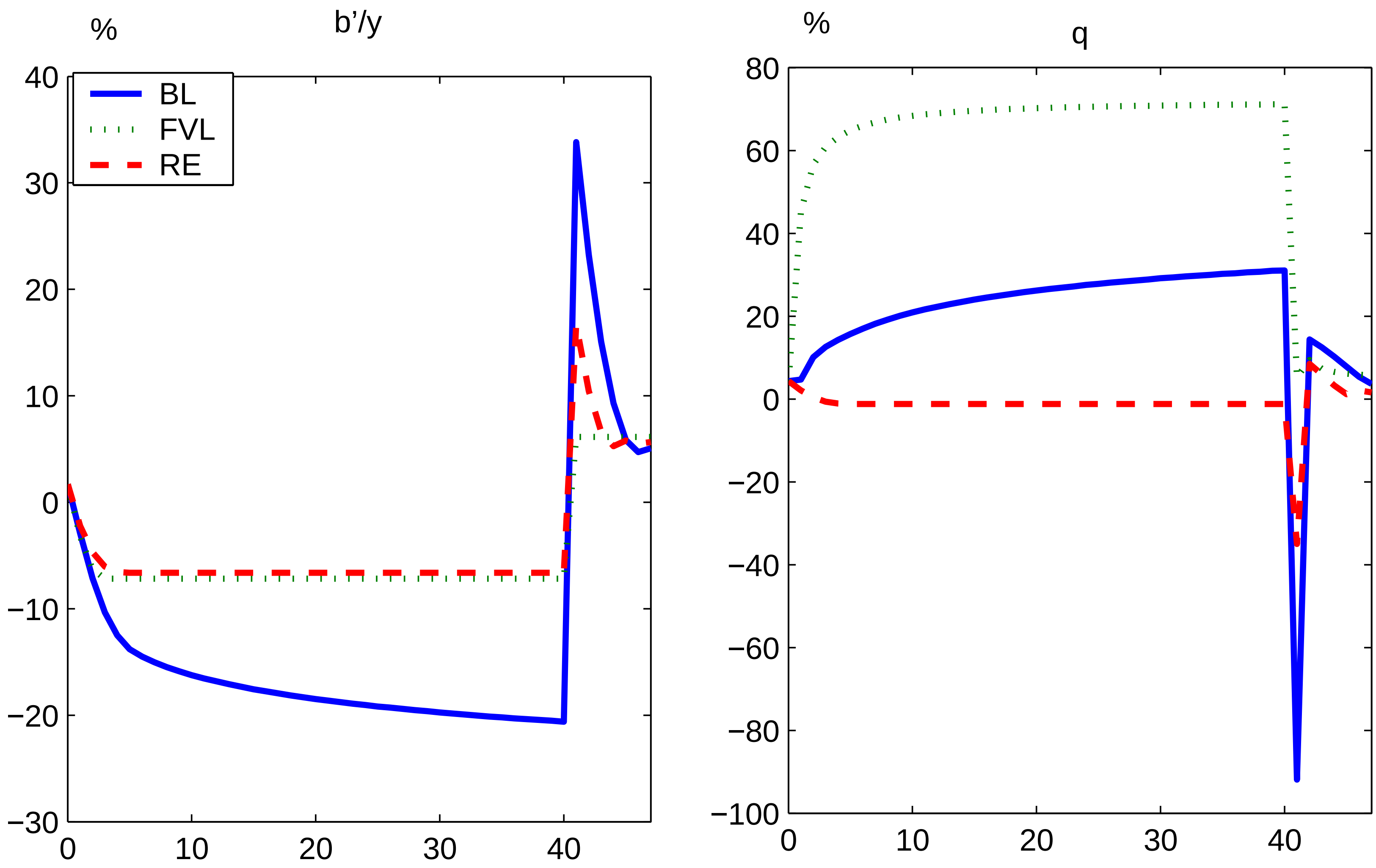
- Expected path of b'/y, q, c and $GSF/y = (b'/R - b)/y$ conditional on $y_1 = 1$, $b_1 = -0.345$, history κ^T, and sequence of beliefs.
  - Expected values taken with probs. defined by this law of motion:

$$\chi_{t+1}(b', z') = \sum_b \sum_z \chi_t(b, z)\pi(z'|z)I_t(b', b, z, \kappa_t)$$

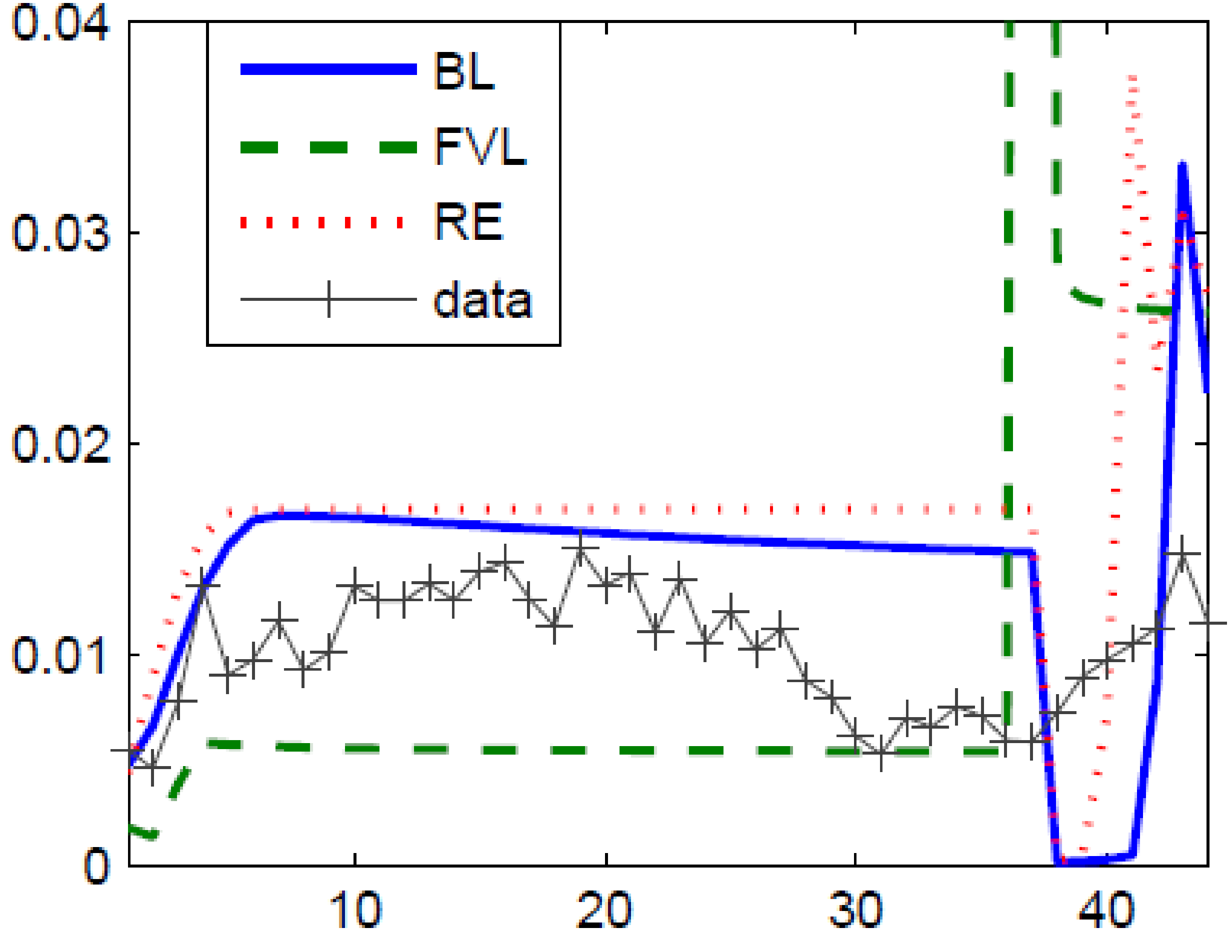
where

$$I_t(b', b, z, \kappa_t) = \begin{cases} 1 & \text{if } b' = h_t\left(b, z, \kappa_t; f(F^s|\kappa^t)\right) , \\ 0 & \text{otherwise.} \end{cases}$$

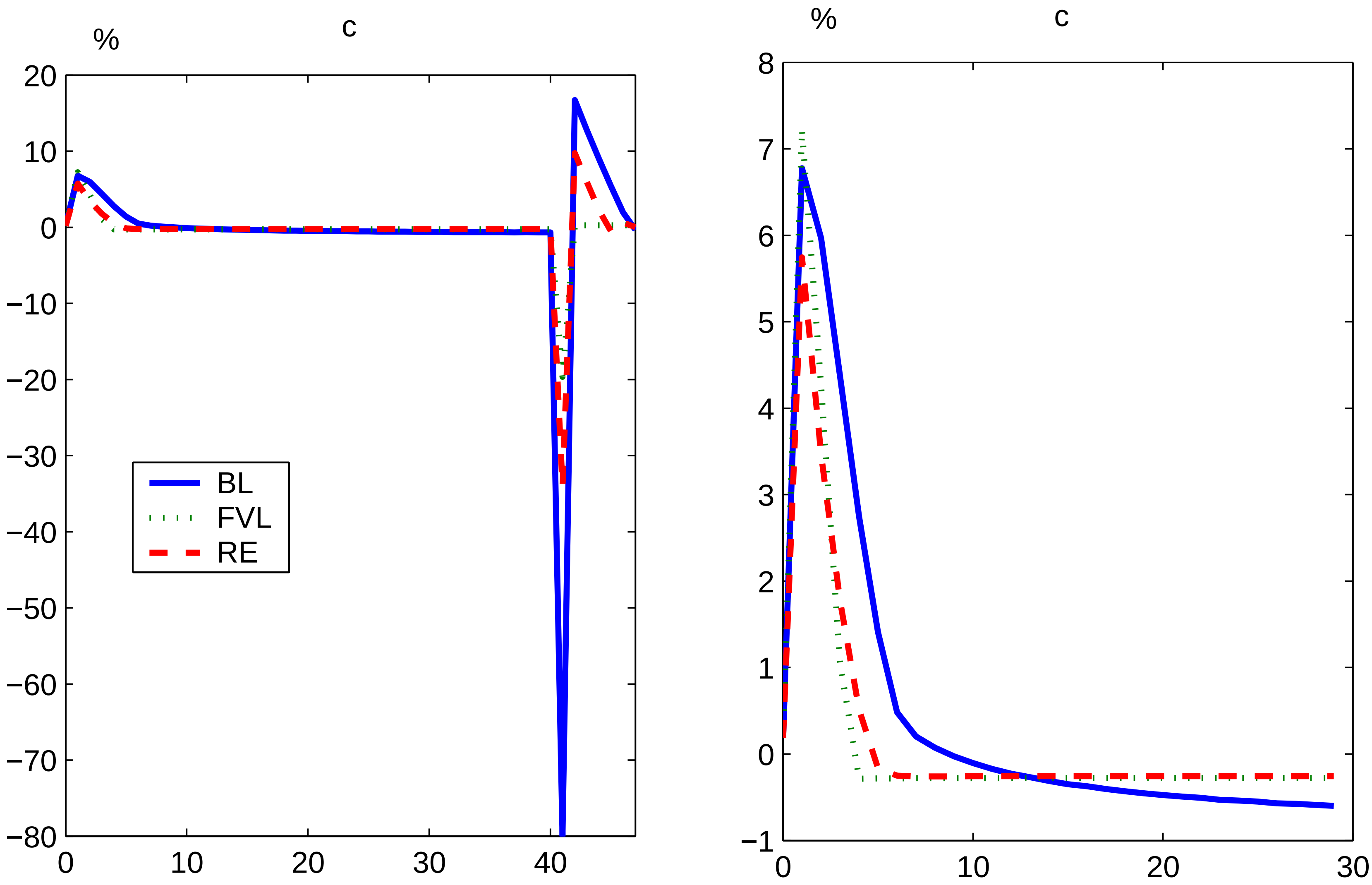
Forecast Functions: Bonds and Land Price



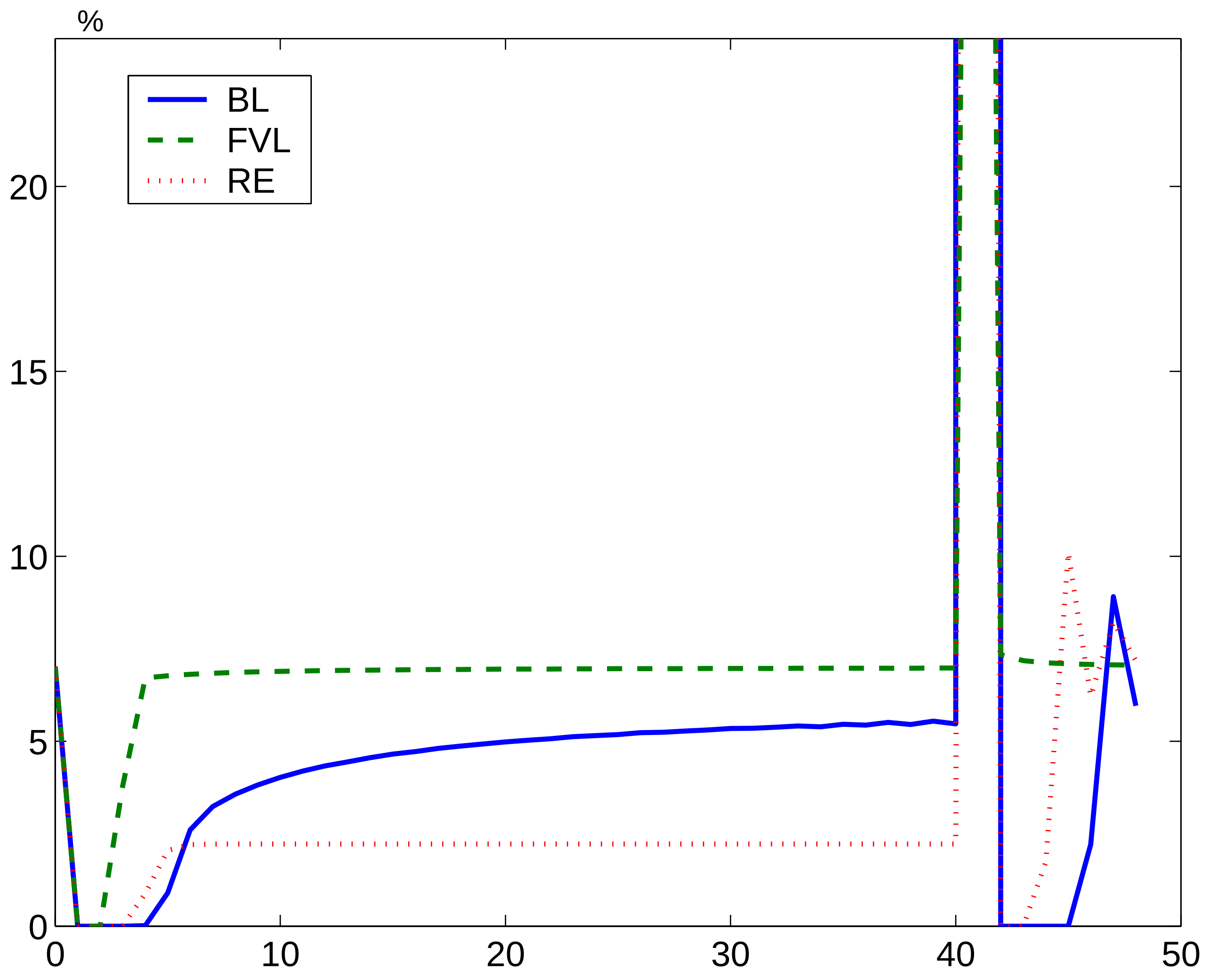
Forecast Functions: Expected Excess Returns



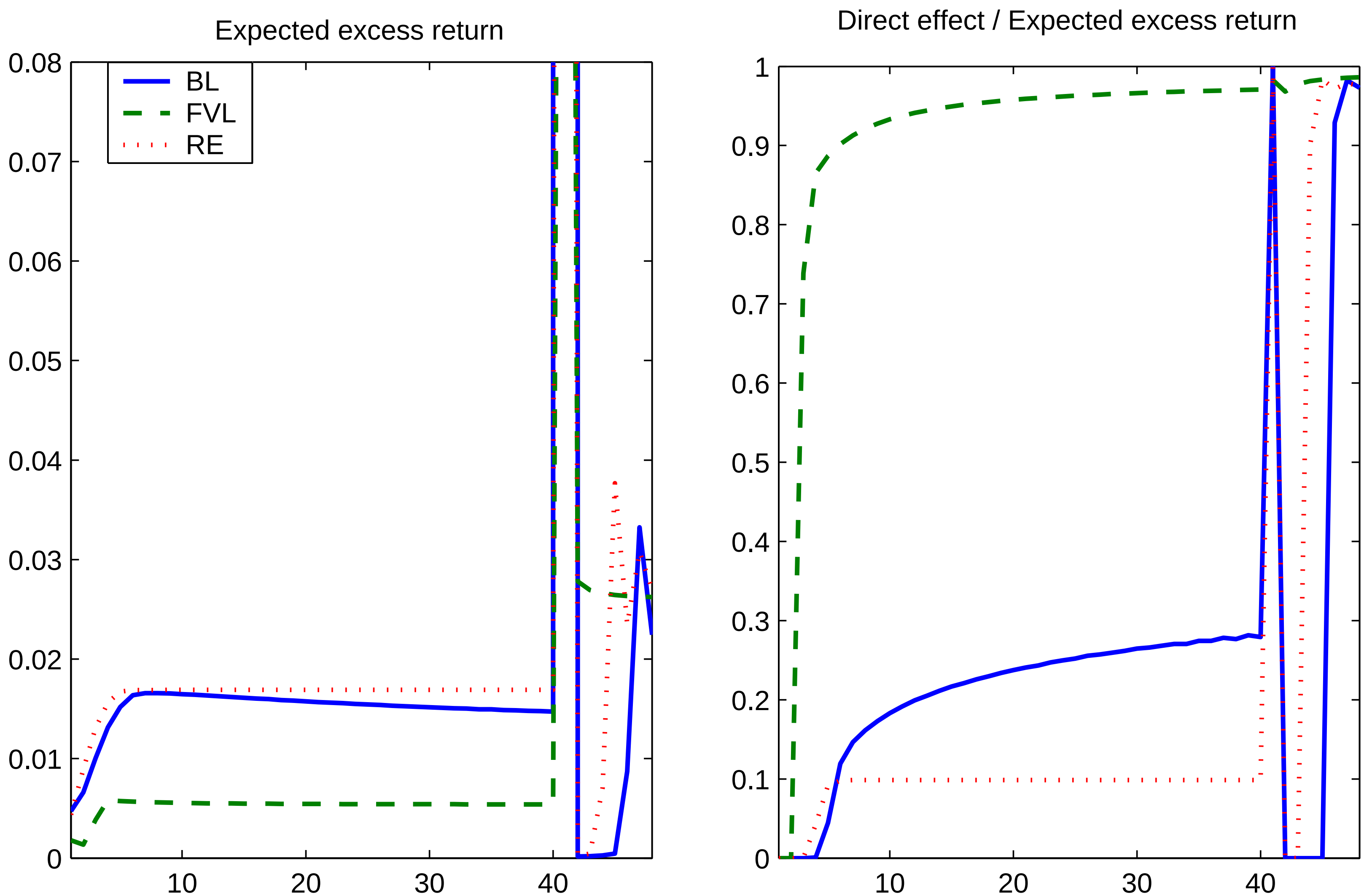
Forecast Functions: Consumption



Interest Rate Premium: $\frac{\mu_t}{u'(c_t)-\mu_t}$



Asset Price Dynamics



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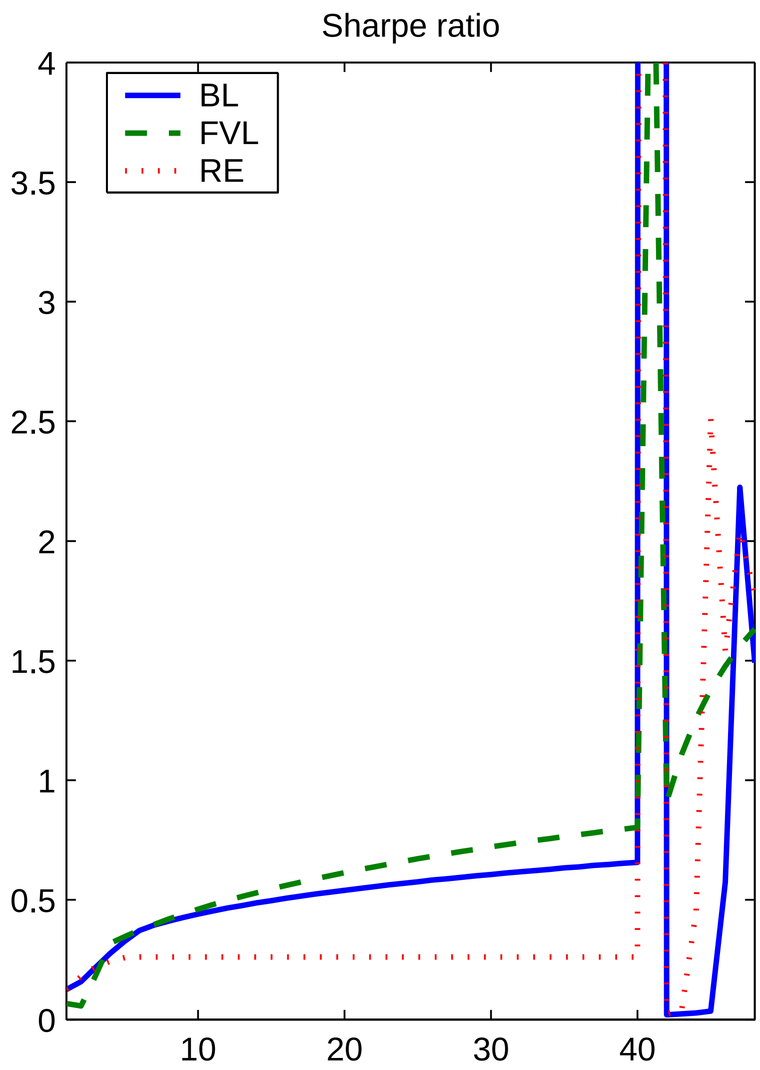
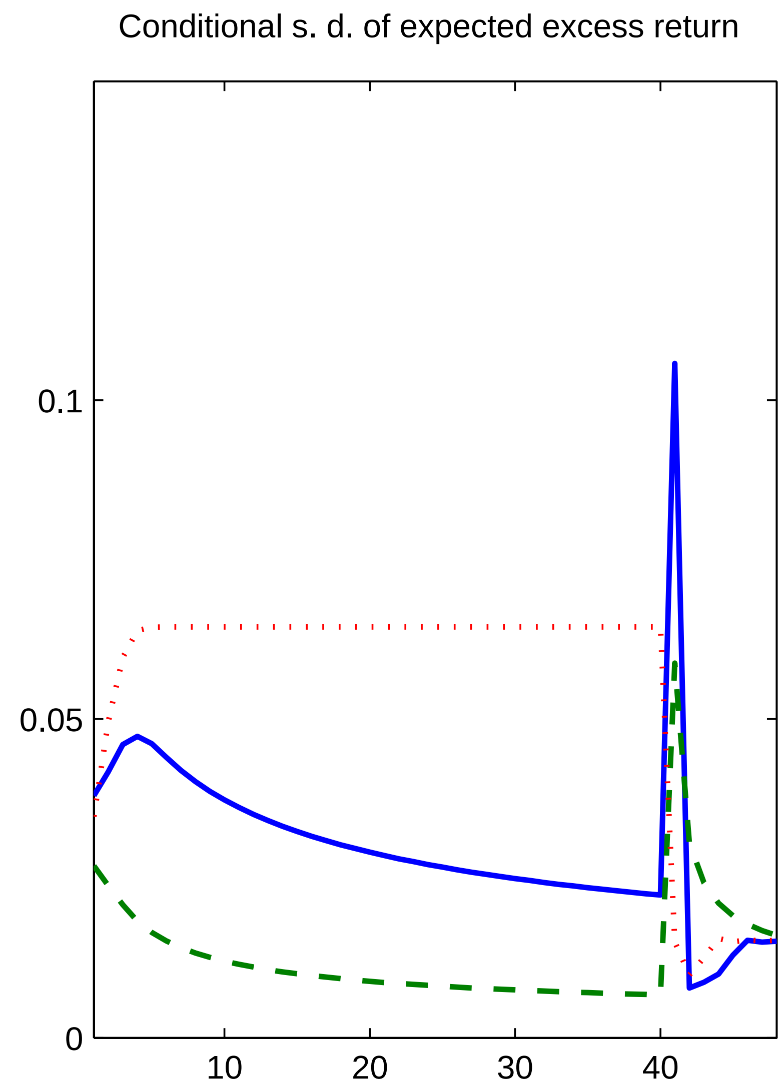




Turning Points

	(1) Data	(2) RE	(3) FVL	(4) BL
Peak of Optimism:				
$E[(b/y)_{40} - (b/y)_0]$	-0.355	-0.083	-0.089	-0.223
$E[(ql/y)_{40} - (ql/y)_0]$	0.280	-0.025	0.305	0.122
Financial Crisis:				
$E[(b/y)_{48} - (b/y)_{40}]$	0.023	0.122	0.133	0.254
$E[(ql/y)_{48} - (ql/y)_{40}]$	-0.149	0.013	-0.305	-0.121

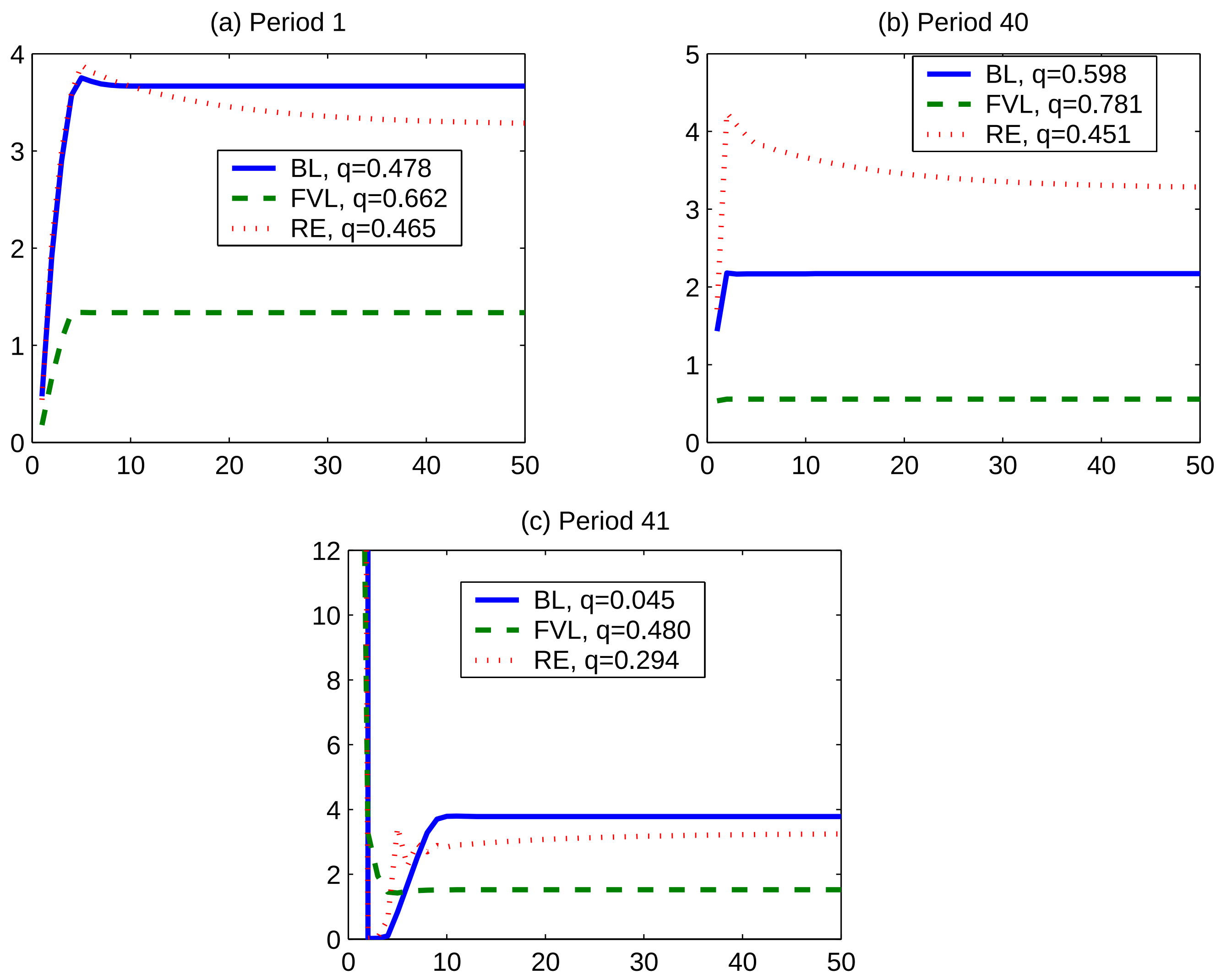
- Learning model can explain 63 (44) percent of the increase in household debt (land price) observed in the data.
- Amplification both upswing and downswing.
- Interaction of learning with debt-deflation generates much larger effects than RE or FVL.

Projected Excess Returns

- Expected excess returns for 50 periods ahead of three initial dates t=1, 40, and 41
  - Use beliefs and associated AUOP for each date.
  - Condition on bond holdings predicted for each initial date by the forecast functions.

$$q_t = E_t^s \left[\sum_{j=0}^{\infty} \left(\prod_{i=0}^{j} \left(\frac{1}{E_t^s [R_{t+1+i}^q]} \right) \right) z_{t+1+j} g'(1) \right]$$

Projected Excess Returns



Sensitivity Analysis: Priors

	BL	(1) $n_0 = 1$	(2) $n_0 = 0.01$	(3) $n_0^{hh} = 0.54$, $n_0^{ll} = 0.54$	(4) $n_0^{ll} = 68$, $n_0^{lh} = 1$
$E[(b/y)_{40} - (b/y)_0]$	-0.223	-0.087	-0.243	-0.222	-0.221
$E[(ql/y)_{40} - (ql/y)_0]$	0.122	-0.020	0.142	0.121	0.121
$E[(b/y)_{48} - (b/y)_{40}]$	0.254	0.137	0.274	0.253	0.254
$E[(ql/y)_{48} - (ql/y)_{40}]$	-0.121	-0.006	-0.141	-0.120	-0.123

- In general, the larger the boom, the larger the bust.
- $n_0 = 1$ (Uniform priors): Qualitatively similar, quantitatively weaker
- $n_0 \downarrow$: more debt and larger asset price boom

Sensitivity Analysis: Other Parameters

	BL	(1) $R = 1.0098$	(2) $\kappa^l = 0.75$	(3) $\kappa^h = 0.8$	(4) $\beta = 0.95$
$E[(b/y)_{40} - (b/y)_0]$	-0.223	-0.248	-0.240	-0.143	-0.237
$E[(ql/y)_{40} - (ql/y)_0]$	0.122	0.158	0.140	0.120	0.140
$E[(b/y)_{48} - (b/y)_{40}]$	0.254	0.208	0.157	0.175	0.175
$E[(ql/y)_{48} - (ql/y)_{40}]$	-0.121	-0.038	-0.059	-0.120	0.098

- Results largely robust to other parameter changes.

Conclusions

- Examined effects of financial innovation in an environment with imperfect information and collateral constraints.
- Waves of optimism and pessimism, combined with Fisherian amplification, explain 63% of debt growth and 44% of rise in land values followed by crash
- Interaction of informational friction and Fisherian Deflation
- Implications for policy debate on financial reform
  - Close supervision of financial intermediaries in early stages of financial innovation (inherent fragility)
  - Limitations of “macroprudential” taxes or fees designed to manage systemic risk
  - Risk of pessimistic beliefs in post-new-regulation era