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Interest Rate Dynamics, Variable-Rate Loan Contracts, and the Business Cycle

Patrick A. Pintus¹

Yi Wen^{2,3} Xiaochuan Xing³

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RIDGE Workshop on Macroeconomic Crises

UBA-IIEP, Buenos Aires December 18, 2015

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Borrowing Cost of US firms

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• Interest rate at which US firms borrow has two features:

(*i*) it is countercyclical

(*ii*) it is an inverted leading indicator: low interest rate forecasts future booms

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Borrowing Cost of US firms

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(i) it is countercyclical

(ii) it is an inverted leading indicator: low interest rate forecasts future booms

• Last feature is a long-standing puzzle: King and Watson (1996)

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Borrowing Cost of US firms

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(i) it is countercyclical

- (*ii*) it is an inverted leading indicator: low interest rate forecasts future booms
- Last feature is a long-standing puzzle: King and Watson (1996)
- One-sector RBC model at odds with both (i) and (ii)

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Borrowing Cost of US firms

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(i) it is countercyclical

- (*ii*) it is an inverted leading indicator: low interest rate forecasts future booms
- Last feature is a long-standing puzzle: King and Watson (1996)
- One-sector RBC model at odds with both (*i*) and (*ii*)
- 2-sector RBC model: Boldrin, Christiano, and Fisher (2001)

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Empirical VAR

• IRFs with investment first:

Response of Investment to Investment



Response of Land Price to Investment



Response of Output to Investment



Response of Debt to Investment



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Empirical VAR Ctnd

• IRFs with investment first:

Response of Worked Hours to Investment



Response of Inverse Investment Price



Response of Consumption to Investment



Response of Borrowing Interest Rate to Investment



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Inverted Leading Indicator

• Lead-lag correlations:



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What We Find

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• Show that a Kiyotaki-Moore model accounts for (i) and (ii)

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- Key assumption: loan contract with variable interest rate

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- Twofold contributions: theory and empirics

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- Twofold contributions: theory and empirics
- Sunspot equilibria (local and global) are very pervasive

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- Twofold contributions: theory and empirics
- Sunspot equilibria (local and global) are very pervasive
- Sunspot shocks to investment quantitatively important
- Sunspot model has better fit than model with unique eqm

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Related Literature

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- Endogenous collateral constraints: Kiyotaki-Moore (1997), Iacoviello (2005), Iacoviello-Neri (2010), Pintus-Wen (2013), Liu-Wang-Zha (2013), Guerrieri-Iacoviello (2015) Justiniano-Primiceri-Tambalotti (2015a,b)
- Sunspots under collateral constraints: Cordoba-Ripoll (2004), Benhabib-Wang (2013), Liu-Wang (2014)
- Sentiments unsecured credit: Benhabib-Wang-Wen (2015) Azariadis-Kaas-Wen (2015)
- Lead-lag correlations: Backus-Kehoe-Kydland (1994), Gomme-Kydland-Rupert (2001), Kydland-Rupert-Sustek (2015)

Road Map

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• Motivation \checkmark

- Global sunspot equilibria in version of Pintus-Wen (2013)
- Quantitative model based on Liu-Wang-Zha (2013)
- Bayesian estimation results on US data 1975-2010
- · Concluding remarks

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Representative Lender

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- This talk: risk-neutral lender, no capital, linear technology ⇒ analytical solution
- In the paper: more general model

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Representative Lender

- This talk: risk-neutral lender, no capital, linear technology ⇒ analytical solution
- In the paper: more general model
- Representative lender solves:

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \tilde{\beta}^t \{ \tilde{C}_t + \psi \tilde{L}_t \}$$

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$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \tilde{\beta}^t \{ \tilde{C}_t + \psi \tilde{L}_t \}$$

• subject to budget constraint:

$$\tilde{C}_t + Q_t(\tilde{L}_{t+1} - \tilde{L}_t) + B_{t+1}^l \le R_t B_t^l$$

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Representative Borrower

• Representative borrower solves:

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \log C_t$$

subject to

$$C_t + Q_t(L_{t+1} - L_t) + R_t B_t^l \le B_{t+1}^l + L_t$$
$$\mathbb{E}_t R_{t+1} B_{t+1}^l \le \theta_t \mathbb{E}_t Q_{t+1} L_{t+1}$$

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• Note that interest payment $R_t B_t^l$ responds to shocks

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- Note that interest payment $R_t B_t^l$ responds to shocks
- Land in fixed supply so land market clears if $L_t + \tilde{L}_t = \bar{L}$

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First-Order Conditions

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- From lender's: $Q_t = Q \equiv \beta/(1-\tilde{\beta})$ and $\mathbb{E}_t R_{t+1} = \tilde{\beta}^{-1}$
- Borrower's FOC and budget constraint then become:

$$\Lambda_t = \mathbb{E}_t X_{t+1} \Lambda_{t+1}$$

$$C_t + Q(1 - \tilde{\beta})L_{t+1} = X_t L_t$$
 where $X_t \equiv 1 + Q(1 - \tilde{\beta}R_t)$

• Closed-form solutions for borrower's choices: $C_t = (1 - \beta)X_tL_t$ and $Q(1 - \tilde{\beta})L_{t+1} = \beta X_tL_t$

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Analytical Example of Global Sunspot Equilibria

Proposition

There exist global sunspot equilibria such that the dynamics of the land stock allocated to borrower follows

$$L_{t+1} = [1 + Q(1 - \tilde{\beta}R_t)]L_t$$

for all $t \ge 0$, given $L_0 > 0$, where $R_t = \tilde{\beta}^{-1}(1 + \varepsilon_t)$ and sunspot innovation ε_t is an i.i.d. random variable with zero mean

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Predetermined Interest Rate

• Contrast this with predetermined interest rate economy:

$$C_t + Q(L_{t+1} - L_t) + R_{t-1}B_t^l \le B_{t+1}^l + L_t$$

 $R_t B_{t+1}^l \le QL_{t+1}$
 $ilde{C}_t + Q(ilde{L}_{t+1} - ilde{L}_t) + B_{t+1}^l \le R_{t-1}B_t^l$

• Interest payment due in *t* now **predetermined**, interest rate entering credit constraint variable but known in *t*

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• Such an economy is always in steady state absent fundamental shocks:

interest rate fixed at $R_t = \tilde{\beta}^{-1}$

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Variable Interest Rate

• In contrast, output growth rate and level fluctuate:



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Occasionally Binding Constraint

30 35 40 45 50

30 35 40 45 50

• Sunspot equilibria with negative skewness:



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• Under variable interest rate, credit demand and supply are:

Intuition

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$$B_{t+1}^{d} = \tilde{\beta}QL_{t+1}, \ B_{t+1}^{s} = QL_{t+1} - \beta X_{t}L_{t}, \ X_{t} \equiv 1 + Q(1 - \tilde{\beta}R_{t})$$

Intuition

• Under variable interest rate, credit demand and supply are: $B_{t+1}^d = \tilde{\beta}QL_{t+1}, B_{t+1}^s = QL_{t+1} - \beta X_t L_t, X_t \equiv 1 + Q(1 - \tilde{\beta}R_t)$



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• Bottom line: sunspot equilibria under variable interest rate because of **aggregate credit-demand externality**

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- Pecuniary externality does not generate sunspot equilibria

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- In the paper:

local sunspot equilibria in more general version of model

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- In the paper: local sunspot equilibria in more general version of model
- Related to literature on sentiments: Benhabib, Wang and Wen (2015)

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• In the paper: local sunspot equilibria in more general version of model

- Related to literature on sentiments: Benhabib, Wang and Wen (2015)
- Sunspots even though **secured** credit, unlike in Azariadis, Kaas and Wen (2015)

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• We introduce variable-rate loans in Liu-Wang-Zha (2013)

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- Model similar to that of Pintus-Wen (2013)
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Quantitative Model

- We introduce variable-rate loans in Liu-Wang-Zha (2013)
- Model similar to that of Pintus-Wen (2013)
- Additional features typical of current DSGE models:
 - consumption habits
 - investment adjustment costs
 - productivity growth

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- Model similar to that of Pintus-Wen (2013)
- Additional features typical of current DSGE models:
 - consumption habits
 - investment adjustment costs
 - productivity growth
- Shocks:
 - discount rate, land demand, labor supply
 - production technology (transitory and permanent)
 - investment technology (transitory and permanent)
 - collateral (leverage)

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Household/Lender

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• Household solves:

$$\max \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t A_t (\ln(C_{ht} - \gamma_h C_{ht-1}) + \varphi_t \ln L_{ht} - \psi_t N_{ht}) \right]$$

where
$$A_t = A_{t-1}(1 + \lambda_{at})$$
,
 $\ln \lambda_{at} = \rho_a \ln \lambda_{at-1} + (1 - \rho_a) \ln \overline{\lambda}_a + \sigma_a \varepsilon_{a,t}$

• subject to budget constraint:

$$C_{ht} + q_{lt}(L_{ht} - L_{ht-1}) + \frac{B_t}{R_t} \le w_t N_{ht} + B_{t-1}$$

where $B_{t-1} = R_{t-1}B_{t-1}^{l}$ denotes interest payment (hence **predetermined** in original model)

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Entrepreneur/Borrower

• Entrepreneur solves:

$$\max \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t \ln(C_{et} - \gamma_e C_{et-1}) \right]$$

• subject to technology constraint:

$$Y_{t} = Z_{t} (L_{et-1}^{\phi} K_{t-1}^{1-\phi})^{\alpha} N_{et}^{1-\alpha}$$

where
$$Z_t = \nu_{zt} Z_t^p$$
, $Z^p = Z_{t-1}^p \lambda_{zt}$,
 $\ln \lambda_{zt} = \rho_z \ln \lambda_{zt-1} + (1 - \rho_z) \overline{\lambda}_z + \sigma_z \varepsilon_{zt}$,
 $\ln \nu_{zt} = \rho_{\nu_z} \ln \nu_{zt-1} + \sigma_{\nu_z} \varepsilon_{\nu_z t}$

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Entrepreneur/Borrower Ctnd

• capital accumulation constraint:

$$K_t = (1-\delta)K_{t-1} + \left(1 - \frac{\Omega}{2}\left(\frac{I_t}{I_{t-1}} - \bar{\lambda}_I\right)^2\right)I_t$$

• budget constraint:

$$C_{et} + q_{lt}(L_{et} - L_{et-1}) + B_{t-1} = Y_t - \frac{I_t}{Q_t} - w_t N_{et} + \frac{B_t}{R_t}$$

where
$$Q_t = Q_t^p \nu_{qt}$$
, $Q^p = Q_{t-1}^p \lambda_{qt}$,
 $\ln \lambda_{qt} = \rho_q \ln \lambda_{qt-1} + (1 - \rho_q) \overline{\lambda}_q + \sigma_q \varepsilon_{qt}$,
 $\ln \nu_{qt} = \rho_{\nu_q} \ln \nu_{qt-1} + \sigma_{\nu_q} \varepsilon_{\nu_q t}$

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Entrepreneur/Borrower Ctnd

• collateral constraint:

$$B_t \le \theta_t \mathbb{E}_t [q_{lt+1} L_{et} + q_{kt+1} K_t]$$

where
$$\ln \theta_t = \rho_\theta \ln \theta_{t-1} + (1 - \rho_\theta) \ln \overline{\theta} + \sigma_\theta \varepsilon_{\theta t}$$

• Variable-rate economy has instead:

$$C_{ht} + q_{lt}(L_{ht} - L_{ht-1}) + B_t^l \le w_t N_{ht} + R_t B_{t-1}^l$$

$$C_{et} + q_{lt}(L_{et} - L_{et-1}) + R_t B_{t-1}^l = Y_t - \frac{I_t}{Q_t} - w_t N_{et} + B_t^l$$
$$\mathbb{E}_t[R_{t+1}]B_t^l \le \theta_t \mathbb{E}_t[q_{lt+1}L_{et} + q_{kt+1}K_t]$$

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Lead-lag Correlations

• Conditional on land price shock in determinate model:



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• Conditional on land price shock in data:



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• Conditional on investment sunspot shock in indet. model:



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• Conditional on investment shock in data:



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Estimation Strategy

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• We estimate **hybrid** versions of both determinate and indeterminate models

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Estimation Strategy

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- We estimate **hybrid** versions of both determinate and indeterminate models
- Assumption:

fraction of variable-rate loans is given by $\omega \in (0, 1)$

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Estimation Strategy

- We estimate **hybrid** versions of both determinate and indeterminate models
- Assumption: fraction of variable-rate loans is given by ω ∈ (0, 1)
- Determinacy (indeterminacy) if $\omega < 0.5 \ (\omega > 0.5)$

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Estimation Strategy

- We estimate **hybrid** versions of both determinate and indeterminate models
- Assumption: fraction of variable-rate loans is given by ω ∈ (0, 1)
- Determinacy (indeterminacy) if $\omega < 0.5 \ (\omega > 0.5)$
- We estimate each model using prior from theory: $\omega < 0.5 \text{ vs } \omega > 0.5$

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Estimation Strategy

- We estimate **hybrid** versions of both determinate and indeterminate models
- Assumption: fraction of variable-rate loans is given by ω ∈ (0, 1)
- Determinacy (indeterminacy) if $\omega < 0.5 \ (\omega > 0.5)$
- We estimate each model using prior from theory: $\omega < 0.5 \text{ vs } \omega > 0.5$
- We use same US 1975-2010 dataset as LWZ (2013): consumption, investment, land price, hours, debt, (inverse of) investment price

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Estimated Parameters

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• Liu-Wang-Zha (2013) with ω estimated:

parameters	prior			posterior				
	distribution	mean	s.d.	mode	mean	low	high	
ω	beta	0.167	0.1179	0.5	0.4975	0.4956	0.5	
ρ_a	beta	0.333	0.2357	0.9098	0.9004	0.8667	0.9367	
ρ_{φ}	beta	0.333	0.2357	0.9997	0.9994	0.9988	1	
σ_a	inv. gamma	0.01	∞	0.095	0.1358	0.0552	0.2231	
σ_{φ}	inv. gamma	0.01	∞	0.0459	0.0488	0.0419	0.0561	

• Data pushes towards highest possible value for ω (that is, 0.5)

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Estimated Parameters Ctnd

• Indeterminate model:



parameters	prior			posterior			
	distribution	mean	s.d.	mode	mean	low	high
ρ_a	beta	0.333	0.2357	0.0215	0.2681	0	0.5535
ρ_{φ}	beta	0.333	0.2357	0.9992	0.9986	0.9975	0.9999
σ_{a}	inv gamma	0.01	\sim	0.0033	0.008	0.0012	0.0159
σ_{ω}	inv. gamma	0.01	∞	0.0468	0.05	0.0412	0.0583
σ_{sun}^{φ}	inv. gamma	0.01	∞	0.0099	0.01	0.0075	0.0126

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• Patience shock has much smaller variance, sunspot shock has significant variance

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Estimated Parameters Ctnd

• Indeterminate model:



parameters	prior			posterior			
	distribution	mean	s.d.	mode	mean	low	high
ρ_a	beta	0.333	0.2357	0.0215	0.2681	0	0.5535
ρ_{φ}	beta	0.333	0.2357	0.9992	0.9986	0.9975	0.9999
σ.	inv gamma	0.01	\sim	0.0033	0.008	0.0012	0.0159
σ	inv. gamma	0.01	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	0.0468	0.05	0.0412	0.0583
σ	inv. gamma	0.01	~	0.0099	0.05	0.0075	0.0126
- Sun	inv. gamma	0.01	\sim	0.0077	0.01	0.0075	0.0120

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- Patience shock has much smaller variance, sunspot shock has significant variance
- Note that ω not identified in indeterminate model

Decomposition

Variance Decomposition

• Liu-Wang-Zha (2013) with ω estimated:









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• Indeterminate model:









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• Sunspot shocks explains significant share of volatility for: output, investment, labor hours, credit

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- Sunspot shocks explains significant share of volatility for: output, investment, labor hours, credit
- Discount rate shocks vanish in sunspot model

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- Sunspot shocks explains significant share of volatility for: output, investment, labor hours, credit
- Discount rate shocks vanish in sunspot model
- Productivity shocks more important in sunspot model

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Variance Decomposition Ctnd

- Sunspot shocks explains significant share of volatility for: output, investment, labor hours, credit
- Discount rate shocks vanish in sunspot model
- Productivity shocks more important in sunspot model
- Indeterminacy alters impact of fundamental shocks

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Variance Decomposition Ctnd

- Sunspot shocks explains significant share of volatility for: output, investment, labor hours, credit
- Discount rate shocks vanish in sunspot model
- Productivity shocks more important in sunspot model
- Indeterminacy alters impact of fundamental shocks
- Land price volatility entirely driven by land demand shocks (in both models)

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- Sunspot shocks explains significant share of volatility for: output, investment, labor hours, credit
- Discount rate shocks vanish in sunspot model
- Productivity shocks more important in sunspot model
- Indeterminacy alters impact of fundamental shocks
- Land price volatility entirely driven by land demand shocks (in both models)
- Land demand shocks explain volatility of land price and interest rate only in sunspot economy

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Model Fit

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• Sunspot model dominates LWZ (determinate) model:

	LWZ	Hybrid LWZ	Sunspot	Hybrid Sunspot
Log marg. data density	2354.75	2359.84	2468.28	2468.59
Model posterior prob.	10^{-50}	10^{-48}	0.42	0.58

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• Sunspot model dominates LWZ (determinate) model:

	LWZ	Hybrid LWZ	Sunspot	Hybrid Sunspot
Log marg. data density	2354.75	2359.84	2468.28	2468.59
Model posterior prob.	10^{-50}	10^{-48}	0.42	0.58

• Pure and hybrid sunspot models not discriminated

Conclusion

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- We study versions of standard models with collateral-constrained borrowing
- We show that secured credit generates financial instability
- Business cycles driven by animal spirits pervasive under variable-rate loan contracts
- Estimation on US data 1975-2010 favors sunspot model
- · Land demand shock explains entirely land price volatility

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• Results could be relevant for household debt

• First-order effects on monetary policy transmission

• Interbank loan market (secured + variable-rate)

• Learnability of sunspot equilibria

Impulse Responses



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• land demand shock in fixed-rate (det.) economy:



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• land demand shock in variable-rate (indet.) economy:



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• land demand shock in variable-rate (indet.) economy:



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• investment sunspot shock in variable-rate (indet.) economy: ΕI 0.03 0.15 0.15 0.1 0.1 0.02 0.05 0.05 0.01 0 0 -0.05 -0.05 10 20 30 10 20 30 10 20 30 к в BI 0.03 0.15 0.08 0.1 0.06 0.02 0.05 0.04 0.01 0 0.02 -0.05 0 10 20 30 10 20 30 10 20 30 x 10⁻³ R Ν W 0.01 0.03 10 0 0.02 5 -0.01 0.01 0 -0.02 0 -0.03 -0.01 30 10 20 30 10 20 10 20 30

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investment sunspot shock in variable-rate (indet.) economy: 10 **x** 10⁻³ 10 ~ 10⁻³ С Ce Ch 0.06 5 0.04 0 0.02 0 -5 0 -5 10 20 30 10 20 30 10 20 30 Le Lh QI 0.4 0.01 0.3 0.005 0.2 -0.05 0.1 0 -0.1 20 10 30 10 20 30 10 20 30 6 - 10⁻³ Qk 2 0 -2 10 20 30

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parameters	prior			posterior			
	distribution	mean	s.d.	mode	mean	low	high
ω	beta	0.167	0.1179	0.5	0.4975	0.4956	0.5
γ_h	beta	0.333	0.2357	0.5175	0.5217	0.4673	0.5777
γ_e	beta	0.333	0.2357	0.7688	0.7241	0.5641	0.879
Ω	gamma	2	2	0.1581	0.1692	0.129	0.2108
$100(g_{\gamma} - 1)$	gamma	0.618	0.453	0.4174	0.3987	0.2846	0.5081
$100(\lambda_q - 1)$	gamma	0.618	0.453	1.2188	1.2147	1.078	1.3453
ρ_a	beta	0.333	0.2357	0.9098	0.9004	0.8667	0.9367
ρ_7	beta	0.333	0.2357	0.3897	0.3965	0.2836	0.5115
ρ_{ν_7}	beta	0.333	0.2357	0.2751	0.3049	0.0923	0.5167
ρa	beta	0.333	0.2357	0.5378	0.5349	0.4287	0.6351
ρ_{ν_a}	beta	0.333	0.2357	0.3096	0.3493	0.0555	0.6162
ρ_{φ}^{γ}	beta	0.333	0.2357	0.9997	0.9994	0.9988	1
ρ_{ψ}	beta	0.333	0.2357	0.9877	0.987	0.978	0.9968
ρ_{θ}	beta	0.333	0.2357	0.9809	0.982	0.9757	0.9884
σ_a	inv. gamma	0.01	∞	0.095	0.1358	0.0552	0.2231
σ_z	inv. gamma	0.01	∞	0.0047	0.0047	0.0038	0.0056
σ_{ν_7}	inv. gamma	0.01	∞	0.0038	0.0039	0.0032	0.0046
σ_q	inv. gamma	0.01	∞	0.0043	0.0044	0.0036	0.0052
σ_{ν_a}	inv. gamma	0.01	∞	0.0027	0.0028	0.0021	0.0035
σ_{φ}^{q}	inv. gamma	0.01	∞	0.0459	0.0488	0.0419	0.0561
σ'_{ψ}	inv. gamma	0.01	∞	0.0076	0.0078	0.0068	0.0087
σ_{θ}	inv. gamma	0.01	∞	0.0117	0.0119	0.0106	0.0131

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Estimated Parameters Ctnd

parameters	prior			posterior			
	distribution	mean	s.d.	mode	mean	low	high
γ_{L}	beta	0.333	0.2357	0.4481	0.4492	0.3904	0.506
γ_{e}	beta	0.333	0.2357	0.9962	0.9109	0.7401	0.9999
$\hat{\Omega}$	gamma	2	2	0.0808	0.0839	0.063	0.1037
$100(g_{\gamma} - 1)$	gamma	0.618	0.453	0.2574	0.1887	0.0305	0.3413
$100(\lambda_q - 1)$	gamma	0.618	0.453	1.206	1.1902	1.0618	1.3082
ρ_a	beta	0.333	0.2357	0.0215	0.2681	0	0.5535
ρ_z	beta	0.333	0.2357	0.339	0.3452	0.2424	0.4452
ρ_{ν_7}	beta	0.333	0.2357	0	0.0521	0	0.1145
ρa	beta	0.333	0.2357	0.3202	0.3473	0.2551	0.4469
ρ_{ν_a}	beta	0.333	0.2357	0.3182	0.2484	0.0015	0.4651
ρ_{φ}^{γ}	beta	0.333	0.2357	0.9992	0.9986	0.9975	0.9999
ρ_{ψ}	beta	0.333	0.2357	0.998	0.9955	0.9911	0.9997
ρ_{θ}	beta	0.333	0.2357	0.9895	0.9852	0.9788	0.9923
σ_a	inv. gamma	0.01	∞	0.0033	0.008	0.0012	0.0159
σ_z	inv. gamma	0.01	∞	0.0049	0.005	0.0043	0.0058
σ_{ν_7}	inv. gamma	0.01	∞	0.0031	0.0033	0.0028	0.0039
σ_q	inv. gamma	0.01	∞	0.0054	0.0053	0.0045	0.0061
σ_{ν_a}	inv. gamma	0.01	∞	0.0018	0.002	0.0013	0.0026
σ_{φ}^{2}	inv. gamma	0.01	∞	0.0468	0.05	0.0412	0.0583
σ_{ψ}	inv. gamma	0.01	∞	0.0074	0.0075	0.0066	0.0084
σ_{θ}	inv. gamma	0.01	∞	0.017	0.0169	0.0148	0.019
σ_{sun}	inv. gamma	0.01	∞	0.0099	0.01	0.0075	0.0126

Patience Land demand Labor supply Permanent neutral technology Transitory neutral technology Permanent investment technology Transitory investment technology Collateral Sunspot Consumption 100% 100% 90% 90% 80% 80% 70% 70% 60% 60% 5.0% 50%



Capital price



Interest rate



40% 30% 20% 10% 0% 4 16 24

Wage

Variance Decomposition

40%

30%

20%

10%

0%

э

Pintus, Wen, Xing

Introduction Motivation What We Find Related Literature Road Map

Basic Model

Representative lender Representative borrower First-order conditions Global sunspot equilibria

Quantitative Model

Quantitative Model

Lead-lag Correlations

Estimation Results

Variance Decomposition Model Fit

Conclusion Conclusion Appendix A IRfs

Variance Decomposition Ctnd



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