Estimating Macroeconomic Models of Financial Crises: An Endogenous Regime-Switching Approach

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Motivation

- Global Financial Crisis Proved Costly to Resolve
- Long History of Painful Financial Crises in Emerging Markets
- Large Theoretical Literature in Response
  - Models of Collateral Constraints for Amplification of Shocks
  - Normative Analyses of Inefficiencies from Collateral Constraints
  - *Ex-ante* versus *ex-post* Policies
  - Which Instruments Most Effective
- Still Lack a Concrete Explanation of Why Countries Fall into Crisis
  - Which Shocks (Interest Rate, Technology, Collateral) Trigger Crises?
  - This is an Empirical Issue
  - Can then Return to Policy Questions

The Objective of this Paper

- Formulate a Model with Occasionally Binding Constraint
- Quantitative Analysis of Financial Crises in Mexico
- Address Several Questions
  - Which Shocks Drive Crises? The Same Ones that Drive Normal Cycle?
  - Is there Time Variation in the Importance of those Shocks?
  - How do the Dynamic Responses to Shocks Change between Crises and Normal Times?
- Enables Future Steps: Return to the Theoretical Questions
  - Which Instruments Best Address which Shocks?
  - Counterfactuals: Given Shocks that Drove Crisis in Past, would Policy have Helped?

This Paper

- New Approach to Specifying, Solving, Estimating Models of Crises
  - Financial Crises Rare but Large Events, so Model Must be Non-Linear
  - Provide a Tractable Formulation of Collateral Constraint
  - Develop Methods to Solve and Estimate such a Model
- Collateral Constraint Similar to Kiyotaki and Moore (1997)
  - Limit Total Debt to a Fraction of the Market Value of Physical Capital
  - Unconstrained to Constrained a Stochastic Function of the LTV Ratio
  - Write as Endogenous Regime-Switching Process
    - Two Regimes: Constraint Binds (Crisis) and Doesn't Bind (Normal)
    - Probability of Binding Rises with Leverage (More Debt or Less Collateral)
    - Agents in Model have Rational Expectations
- Estimate via Full-Information Bayesian Methods
  - Estimated Binding Regime Corresponds to Sudden Stop Narrative Dates
  - Fluctuations in Normal Regime Driven by Real Shocks
  - Leverage Shocks most Important in Crisis Regime

Model Overview

- Based Largely on Mendoza (2010)
- Small Open Economy that Borrows from Abroad
- Imported Goods used in Production
- Working Capital Constraint for Labor and Import Payments
- Value of Capital Serves as Collateral
- Pecuniary Externality and Overborrowing
- Regime-Specific Borrowing Constraints
- Endogenously Switch Between Regimes
- Four Types of Shocks: 3 Real, 1 Financial

Preferences and Production

- Representative Household-Firm with Preferences

$$U \equiv \mathbb{E}_0 \sum_{t=0}^{\infty} \left\{ \beta^t \frac{1}{1-\rho} \left(C_t - \frac{H_t^{\omega}}{\omega} \right)^{1-\rho} \right\}$$

- Production uses Capital, Labor, and Imported Intermediate Goods

$$Y_t = A_t K_{t-1}^{\eta} H_t^{\alpha} V_t^{1-\alpha-\eta}$$

- Investment with Adjustment Costs

$$I_t = \delta K_{t-1} + (K_t - K_{t-1}) \left(1 + \frac{\iota}{2} \left(\frac{K_t - K_{t-1}}{K_{t-1}} \right)^2 \right)$$

- Budget Constraint, with $B_t < 0$ as Debt

$$C_t + I_t = Y_t - P_t V_t - \phi r_t \left(W_t H_t + P_t V_t \right) - \frac{1}{(1 + r_t)} B_t + B_{t-1}$$

Collateral Constraint: Motivation

- The Agent Faces a Regime-Specific Collateral Constraint
  - When $s_t = 1$, Borrowing is Constrained (Crisis Regime)
  - When $s_t = 0$, Borrowing is Unconstrained (Normal)
- International Lenders have Stochastic Monitoring
  - In Crisis, Actively Monitor and Enforce Borrowing Constraint
  - In Normal, Don't Actively Monitor and Allow Borrowing
  - Decision to Monitor or Not Depends on Previous Borrowing and Monitoring Shock
  - Key Timing: Monitoring Shock Orthogonal to Structural Shocks

Collateral Constraint: Crisis Regime

- In Crisis Regime, Total Borrowing is a Fraction of Value of Collateral

$$\frac{1}{(1+r_t)}B_t - \phi\left(1+r_t\right)\left(W_t H_t + P_t V_t\right) = -\kappa_t q_t K_t$$

  - Debt and Working Capital Restricted
  - Collateral in the Model is Defined over the Value of Capital
  - Pecuniary Externality: Price and Quantity of Collateral are Endogenous
- Multiplier Associated with Constraint is λ_t

Collateral Constraint: Normal Regime

- In Normal Regime, Borrowing is Unconstrained
    - Collateral Value is Sufficient for International Lenders to Finance all Desired Borrowing
    - No Explicit Constraint on Borrowing
    - Two Forces Limiting Infinite Borrowing
        - Small Debt Elastic Interest Rate Premium
        - Expectations
- The "Borrowing Cushion" is Debt Less the Collateral Value

$$B_t^* = \frac{1}{(1+r_t)} B_t - \phi (1+r_t)(W_t H_t + P_t V_t) + \kappa_t q_t K_t$$

- Small Borrowing Cushion Implies High Leverage Ratio

Endogenous Switching

- In Normal Regime, Probability that Constraint Binds or Not Next Period Depends on Borrowing Cushion and Monitoring Shock

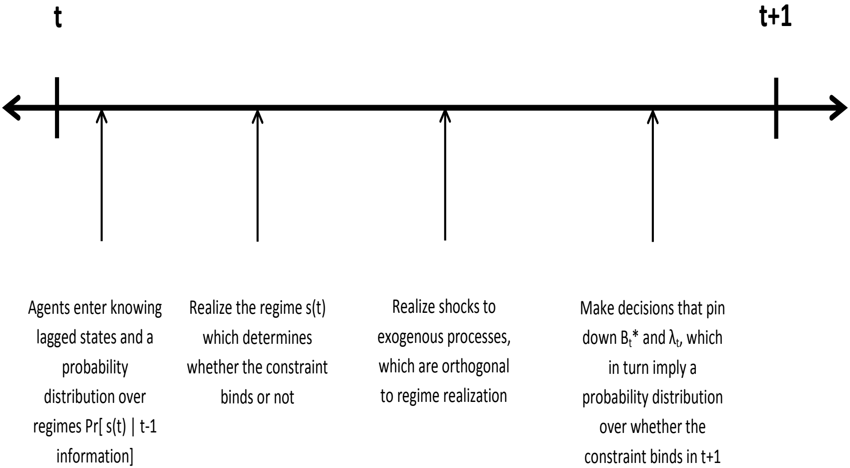
$$s_{t+1} = \Pi\left(B_t^*, \epsilon_{t+1}^M | s_t = 0\right)$$

- In Crisis Regime, Probability that Constraint Binds or Not Next Period Depends on Multiplier

$$s_{t+1} = \Pi\left(\lambda_t, \epsilon_{t+1}^M | s_t = 1\right)$$

- Reformulates Kiyotaki-Moore Idea that Increased Leverage Leads to Binding Collateral Constraints as a Probabilistic Statement
- Timing in model is different than Mendoza (2010)

Timing of the Model



Endogenous Switching

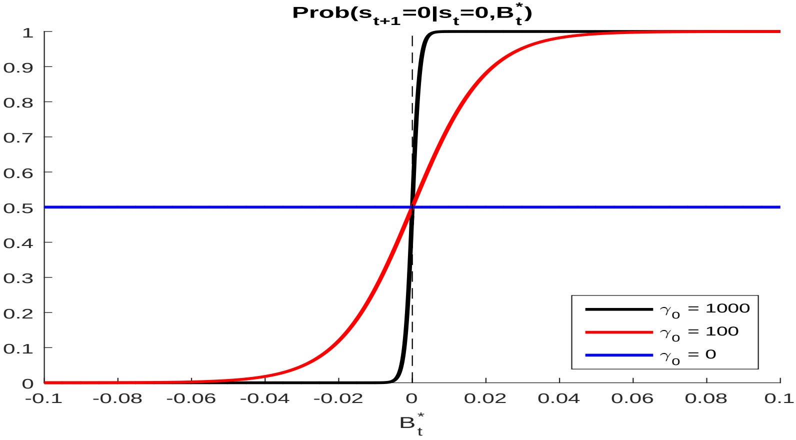
- Assume Π and ϵ_{t+1}^{M} Generate Logistic Distributions

$$\Pr\left(s_{t+1}=1|s_t=0\right)=\frac{\exp\left(-\gamma_0 B_t^*\right)}{1+\exp\left(-\gamma_0 B_t^*\right)}$$

$$\Pr\left(s_{t+1}=0|s_t=1\right)=\frac{\exp\left(-\gamma_1 \lambda_t\right)}{1+\exp\left(-\gamma_1 \lambda_t\right)}$$

- Similar to Davig, et al (2010), Bi and Traum (2014), and Kumhof et al (2015)
- Evidence for γ_0 and γ_1 Key in Estimation
- Slackness Condition is $B_t^* \lambda_t = 0$, will Return to This Later

Form of the Logistic Function



Interest Rates and Exogenous Processes

- Interest Rate Process

$$r_t = r^* + \psi_r \left(e^{\overline{B} - B_t} - 1 \right) + \sigma_w (s_t) \varepsilon_{w,t}$$

- Productivity

$$\log A_t = (1 - \rho_A (s_t)) a (s_t) + \rho_A (s_t) \log A_{t-1} + \sigma_A (s_t) \varepsilon_{A,t}$$

- Terms of Trade

$$\log P_t = (1 - \rho_P (s_t)) p (s_t) + \rho_P (s_t) \log P_{t-1} + \sigma_P (s_t) \varepsilon_{P,t}$$

- Leverage

$$\kappa_t = (1 - \rho_\kappa (s_t)) \kappa (s_t) + \rho_\kappa (s_t) \kappa_{t-1} + \sigma_\kappa (s_t) \varepsilon_{\kappa,t}$$

Solution

- Full Set of Structural Equations: 16 Equilibrium Conditions
  - First-Order Conditions
  - Constraints
  - Exogenous Processes
- Nonlinear Model that Can in Principle be Solved with Global Methods
- This Paper: Compute an Approximate Solution via Perturbation
  - Very Fast Solution that Allows for Likelihood-Based Estimation
  - Show How Rewrite Slackness Condition as Regime-Switching
  - Endogenously Determined Approximation Point between Normal and Crisis Regimes

Regime Switching Slackness Condition

- Recall the Slackness Condition $B_t^* \lambda_t = 0$
- This Condition is Hard to Implement via Local Approximations
- Introduce Indicator Variables $\varphi(s_t) = \nu(s_t) = s_t$
- Slackness Constraint Becomes

$$\varphi(s_t) B_{ss}^* + \nu(s_t)(B_t^* - B_{ss}^*) = (1 - \varphi(s_t)) \lambda_{ss} + (1 - \nu(s_t))(\lambda_t - \lambda_{ss})$$

- Modified Slackness Condition
    - In Normal Regime, $\varphi(0) = \nu(0) = 0$, so $\lambda_t = 0$
    - In Crisis Regime, $\varphi(1) = \nu(1) = 1$, so $B_t^* = 0$

Properties of the Solution

- Extend Perturbation Method of Foerster, et. al. (2016)
- Other Approaches: Lind (2014), Maih (2015), Barthelemy and Marx (2017)
- Approximation Point Ergodic Mean of Regimes

$$P_{ss} = \begin{bmatrix} 1 - \frac{\exp(-\gamma_0 B^*_{ss})}{1+\exp(-\gamma_0 B^*_{ss})} & \frac{\exp(-\gamma_0 B^*_{ss})}{1+\exp(-\gamma_0 B^*_{ss})} \\ \frac{\exp(-\gamma_1 \lambda_{ss})}{1+\exp(-\gamma_1 \lambda_{ss})} & 1 - \frac{\exp(-\gamma_1 \lambda_{ss})}{1+\exp(-\gamma_1 \lambda_{ss})} \end{bmatrix}$$

- General Result: Endogenous Switching Doesn't Appear in First Order
  - First-Order Dynamics Same with Endogenous and Exogenous Probabilities of P_{ss}
  - Precautionary Behavior in the Second Order Solution is Critical
- Expectational Effects Matter for Response to Shocks in Normal Regime
  - Sensitivity of Crises to Debt Cushion
  - Magnitude of Crises
  - Note that this Makes Policy Implications Interesting/Relevant

Estimating the Nonlinear Model

- Second-Order plus Endogenous Probabilities Complicates Estimation
- Rational Expectations
    - Links Parameters Across Regimes and Economic Behavior
    - Two-Step Procedures Inappropriate
    - Agents in the Model Fully Understand Crises Occur and Adjust Behavior
    - Estimated Model Useful for Normative Analysis Precisely because of this Feature of the Model Solution/Estimation
- Identification of Parameters Helped by Rational Expectations
- Procedure for Simultaneous Estimation of Regimes and Parameters
    - Metropolis-Hastings Algorithm
    - Binning and Maih (2015): Unscented Kalman Filter with Sigma Points
- Bayesian Estimation with Diffuse Priors

Data for Estimation

- Data for Mexico from 1981Q1 to 2016Q1
  - Includes Financial Crises of 1982, 1994, 2007
  - Also Periods of Expansion and Recession
- Observables
  - Real GDP Growth
  - Investment Growth
  - Consumption Growth
  - Import Price Growth
  - Interest Rate: EMBI Global + World Interest Rate
- Measurement Errors for all Observables

Quick Recap

- Set up a Small Open Economy Model
  - Hit with 4 Types of Shocks
  - Borrow to Smooth Consumption, Pay for Inputs
  - As Debt Increases Relative to Capital, Probability of a Crisis Increases
  - Crisis Constrains Borrowing
- Developed Solution and Estimation Procedures
  - Endogenous Regime Switching
  - Second Order Solution and Estimation
- Objectives for Estimation
  - Estimate Key Structural Parameters
  - Characterize When in Crisis Regime, Which Shocks Drive Crises
  - Determine which Shocks Drive Standard Fluctuations

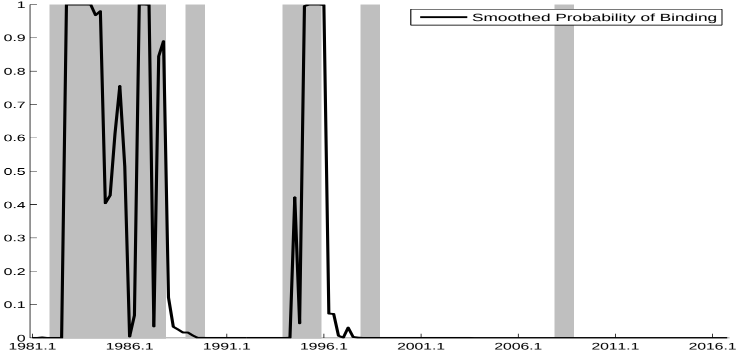
Calibrated Parameters

Parameter	Value
Discount Factor	$\beta = 0.97959$
Risk Aversion	$\rho = 2$
Labor Share	$\alpha = 0.592$
Capital Share	$\eta = 0.306$
Wage Elasticity of Labor Supply	$\omega = 1.846$
Capital Depreciation (8.8% Annually)	$\delta = 0.022766$
Interest Rate Intercept	$r^* = 0.0208352$
Interest Rate Elasticity	$\psi_r = 0.05$
Neutral Debt Level	$\bar{B} = -1.7517$
Mean of TFP Process, Normal Regime	$a(0) = 0$
Mean of Import Price Process, Normal Regime	$p(0) = 0$
Mean of Leverage Process, Normal Regime	$\kappa(0) = 0.15$

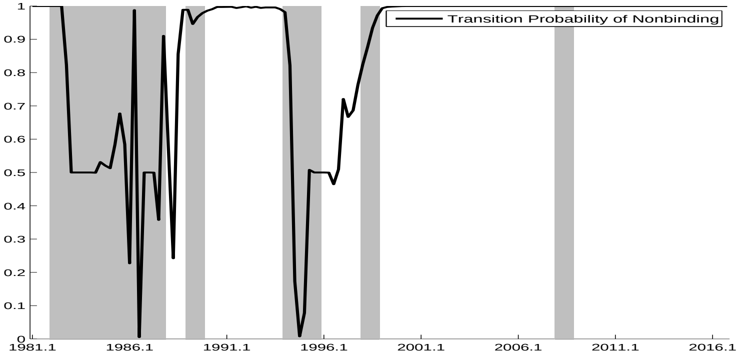
Estimation Results: Key Structural Parameters

		Posterior		
Parameter		Mean	q5	q95
TFP Persistence	$\rho_a(0)$	0.8134	0.7208	0.8843
	$\rho_a(1)$	0.7746	0.5543	0.8968
TOT Persistence	$\rho_p(0)$	0.9637	0.9340	0.9876
	$\rho_p(1)$	0.9260	0.8258	0.9941
Lev Persistence	$\rho_\kappa(0)$	0.6656	0.4152	0.8946
	$\rho_\kappa(1)$	0.7804	0.6728	0.8872
TFP Mean, Crisis	a(1)	-0.0059	-0.0072	-0.0047
TOT Mean, Crisis	p(1)	0.0005	0.0000	0.0013
Lev Mean, Crisis	$\kappa(1)$	0.2305	0.2203	0.2440
Capital Adjust Cost	ι	2.8233	2.8144	2.8360
Working Capital	ϕ	0.3036	0.2697	0.3217
Normal to Crisis Prob	γ_0	89.0076	73.2143	108.1845
Crisis to Normal Prob	γ_1	1.9676	0.0892	5.8921

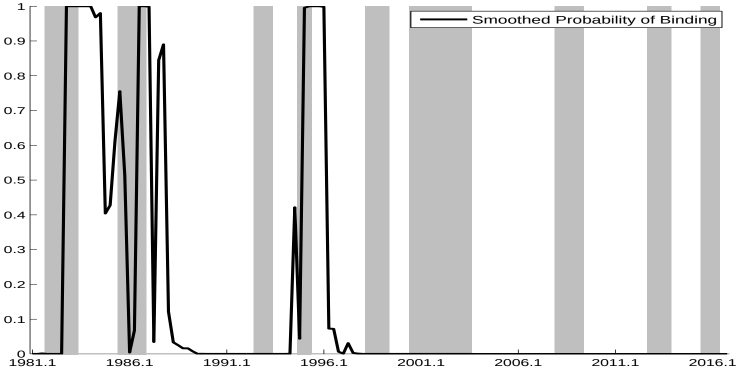
Crises Estimates vs. Reinhart-Rogoff Currency Crisis Dates



Transition Prob. vs. Reinhart-Rogoff Currency Crisis Dates



Crises Estimates vs. OECD Recession Dates



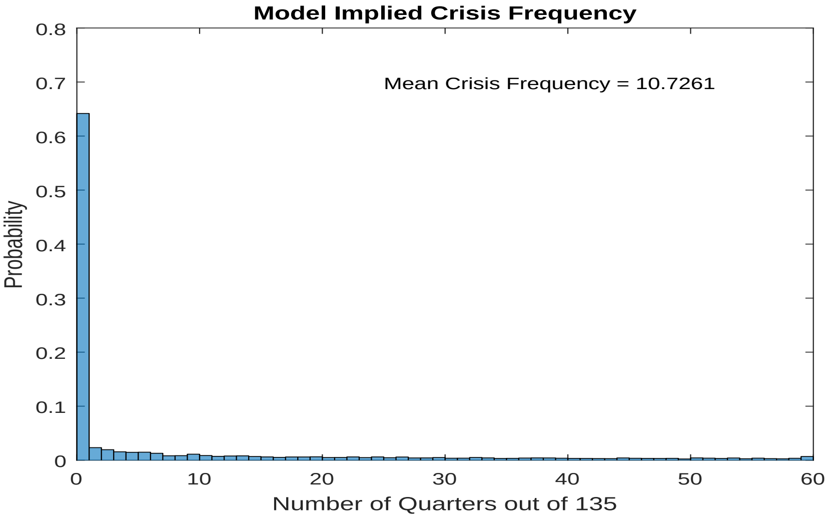
Estimation Results: Shock Standard Deviations

Parameter		Posterior Mean	Posterior q5	Posterior q95
World Interest Rate	$\sigma_w(0)$	0.0007	0.0001	0.0015
	$\sigma_w(1)$	0.0438	0.0332	0.0496
TFP	$\sigma_a(0)$	0.0056	0.0043	0.0068
	$\sigma_a(1)$	0.0091	0.0062	0.0123
TOT	$\sigma_p(0)$	0.0401	0.0338	0.0478
	$\sigma_p(1)$	0.0487	0.0218	0.0766
Leverage	$\sigma_\kappa(0)$	0.0012	0.0001	0.0030
	$\sigma_\kappa(1)$	0.0248	0.0072	0.0419

Importance of Shocks

Shock		Regime	C	I	r	Y
World Interest Rate	$\varepsilon_{w,t}$	Normal	0.0001	0.0128	0.0066	0.0000
Technology	$\varepsilon_{a,t}$	Normal	0.3087	0.2670	0.6390	0.3158
Import Price	$\varepsilon_{p,t}$	Normal	0.6817	0.3777	0.1971	0.6814
Leverage	$\varepsilon_{\kappa,t}$	Normal	0.0095	0.3424	0.1572	0.0027
World Interest Rate	$\varepsilon_{w,t}$	Crisis	0.0074	0.0044	0.3701	0.0145
Technology	$\varepsilon_{a,t}$	Crisis	0.0106	0.0003	0.0004	0.0705
Import Price	$\varepsilon_{p,t}$	Crisis	0.0124	0.0002	0.0003	0.0630
Leverage	$\varepsilon_{\kappa,t}$	Crisis	0.9696	0.9951	0.6291	0.8520

Crisis Frequency



What Drives the Crisis Frequency

Shock		Frequency
All Shocks		10.7261
Individual		
World Interest Rate Only	$\varepsilon_{w,t}$	0.0095
Technology Only	$\varepsilon_{a,t}$	1.8908
Import Price Only	$\varepsilon_{p,t}$	4.5550
Leverage Only	$\varepsilon_{\kappa,t}$	3.0736
Sum		9.5289

Conclusion

- New Approach to Specifying, Solving, Estimating Models of Financial Crises
- Probability Regime Switch Depends on State of Economy
- Endogenous Switching Impacts the Economic Behavior in Qualitatively and Quantitatively Important Ways
- Crisis Regime Corresponds to Narrative Dates
- Leverage Shocks Drive Fluctuations during Financial Crises
- Real Shocks Drive Fluctuations in Normal Regime
- Future Work: Conditional Policy Counterfactuals