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
- Issue: Models with Occasionally Binding Constraints Hard to Solve
    - Usually Requires Slow Global Solution Methods
    - Makes Likelihood-Based Estimation Infeasible

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?

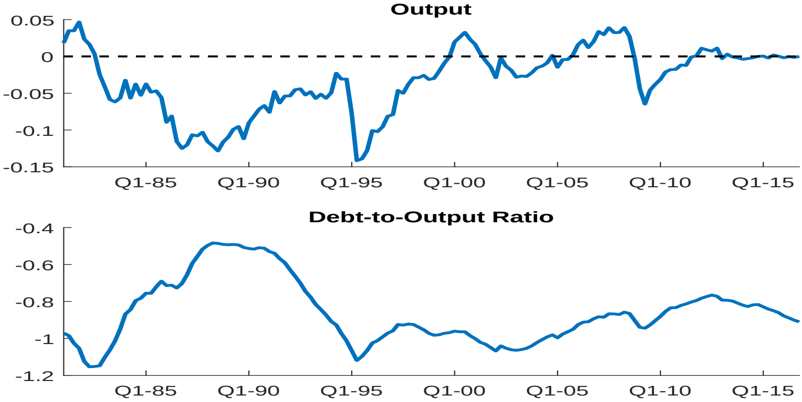
Pre-Crisis and Post-Crisis Consensus on Methodology

- Pre-Crisis: Medium Scale Estimated DSGE Models
  - Estimate Importance of Shocks and Frictions
  - Analyze Policy Questions in this Fully Specified Empirical Framework
- Post-Crisis: Calibrated Models featuring Non-Linear Dynamics
  - Focus on Event-Study Type Analysis
  - Occasionally Binding Borrowing Constraints
- This Paper Bridges the Two Approaches
  - Providing an Empirical Framework: Estimation of Shocks and Frictions
  - Incorporating the Non-Linearities Associated with Financial Crises

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
- Kiyotaki-Moore Type Collateral Constraint
  - 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: Crisis (Constraint Binds) and Normal (Doesn't Bind)
    - Probability of Crisis Rises with Leverage (More Debt or Less Collateral)
    - Agents in Model have Rational Expectations
- Estimate via Full-Information Bayesian Methods
  - Estimated Crisis Regime Corresponds to Sudden Stop Narrative Dates
  - Fluctuations in Normal Regime Driven by Real Shocks
  - Leverage Shocks most Important in Crisis Regime

Output and Debt in Mexico



Outline of Talk

- Introduction
- Model
  - Standard Open Economy Preferences and Production
  - Collateral Constraint as Endogenous Regime-Switching
- Solution and Estimation
  - Solving the Endogenous Switching Model
  - Importance of Non-Linear Methods
  - Estimation Methodology
- Results
  - Crises Dates
  - Which Shocks Drive Crises and Standard Fluctuations
- Conclusion

Model Overview

- 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 $s_t = 1$, in the Crisis Regime and Borrowing is Constrained
  - When $s_t = 0$, in the Normal Regime and Borrowing is Unconstrained
- 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

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

  - 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
    - Debt Elastic Interest Rate Premium
    - Expectations
- The "Borrowing Cushion" is Debt Less the Collateral Value

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

- 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

$$s_{t+1} = \Gamma\left(\epsilon^M_{t+1} | s_t = 0, B^*_t\right)$$

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

$$s_{t+1} = \Gamma\left(\epsilon^M_{t+1} | s_t = 1, \lambda_t\right)$$

- Reformulates Kiyotaki-Moore Idea that Increased Leverage Leads to Binding Collateral Constraints as a Probabilistic Statement
- Note the Difference in Timing

Endogenous Switching

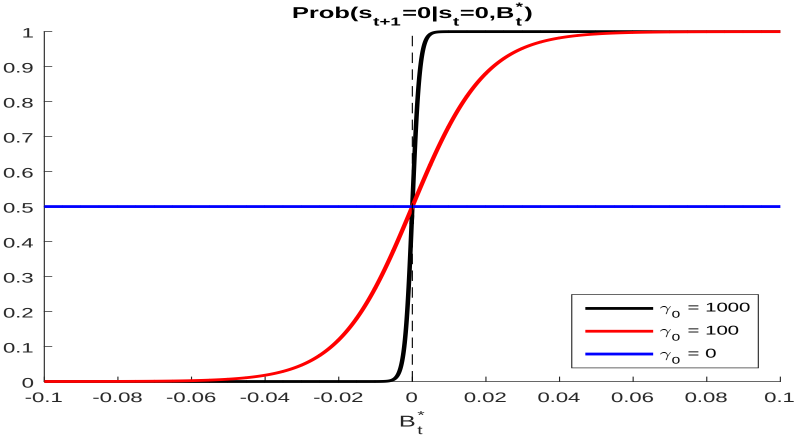
- Assume that ϵ_{t+1}^{M} Distributed to Induce Logistic Distributions

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

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

- Logistic is Common, Parsimonious Formulation
  - Fiscal Policy and Default
  - Davig, et al (2010), Bi and Traum (2014), and Kumhof et al (2015)
- Evidence for γ_0, γ_1 Key in Estimation

Form of the Logistic Function



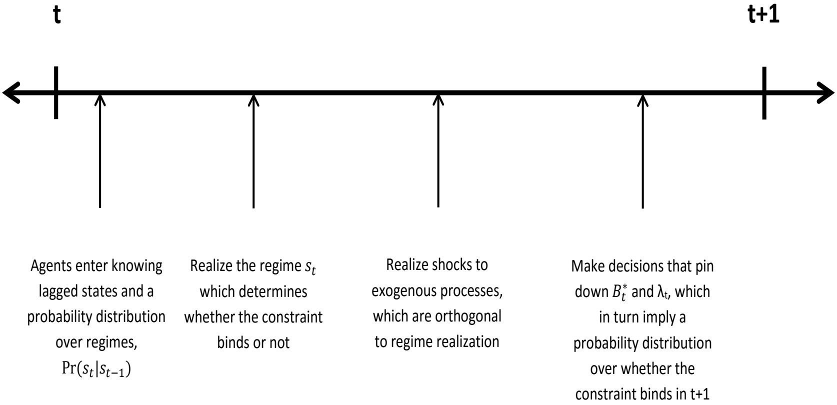
Regime Switching Slackness Condition

- "Typical" Slackness Condition is $B_t^* \lambda_t = 0$
- Need to Adapt to Regime-Switching Framework
- Introduce Indicator Variables $\varphi(s_t) = \nu(s_t) = s_t$
- Regime Switching Slackness Condition

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

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

Timing of the Model



Interest Rates and Exogenous Processes

- Interest Rate Process

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

- 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

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

- Regime-Specific Process for Flexibility in Estimation

Leverage Shocks

- Interested in Role of Leverage Shocks
  - Importance as a Cause of Crises
  - Relative Importance in and Out of Crisis
- Stochastic, Regime-Dependent Restrictions on Leverage

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

- Binding Regime

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

- Non-binding regime

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

Solution

- Full Set of Equilibrium Conditions
  - First-Order Conditions
  - Constraints
  - Regime-Switching Slackness Condition
  - 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
  - Endogenously Determined Approximation Point between Regimes
- Extend Perturbation Method of Foerster, et. al. (2016)
- Other Approaches: Lind (2014), Maih (2015), Barthelemy and Marx (2017)

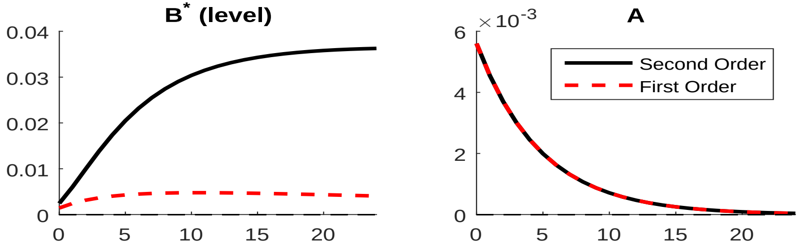
Properties of the Solution

- Approximation Point Ergodic Mean of Regimes

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

- General Result: Endogenous Switching Doesn't Appear in First Order
  - First-Order Dynamics Same with Endogenous and Exogenous Probabilities of $\mathbb{P}_{ss}$
  - 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
  - Crisis Regime Parameters
  - Helps with Identification in Estimation
  - Note that this Makes Policy Implications Interesting/Relevant

Approximation and IRF to TFP Shock



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
- Procedure for Simultaneous Estimation of Regimes and Parameters
  - Metropolis-Hastings Algorithm
  - Binning and Maih (2015): Unscented Kalman Filter with Sigma Points
- Bayesian Estimation with Uniform Priors

Data for Estimation

- Data for Mexico from 1981Q1 to 2016Q4
  - Includes Financial Crises of 1982, 1994, 2007
  - Also Periods of Expansion and Recession
- Observables
  - Real GDP Growth
  - Investment Growth
  - Consumption Growth
  - Interest Rate
  - Trade-Balance-to-Output Ratio
- 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
  - Determine which Shocks Drive Fluctuations
  - How Frequent are Crises?
  - Bonus: Preview Effect of Capital Controls

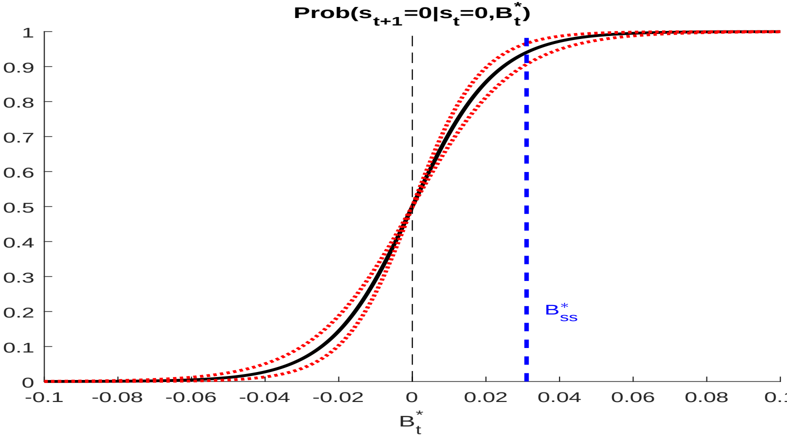
Calibrated Parameters

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	$\delta = 0.022766$
Interest Rate Elasticity	$\psi_r = 0.05$
Debt-to-GDP Ratio	$B_{ss}/Y_{ss} = -0.86$
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	$\kappa^*(0) = 0.15$

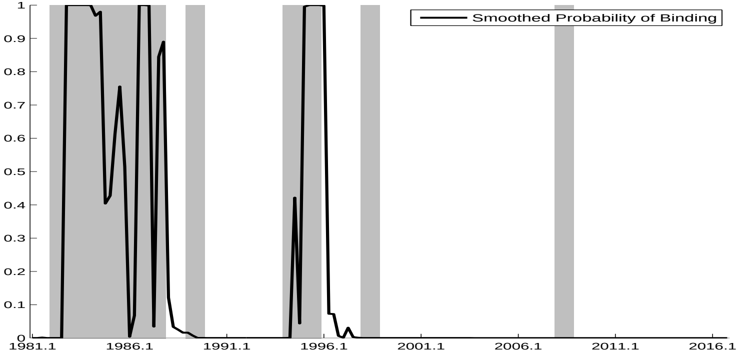
Estimation Results: Key Structural Parameters

Parameter	Prior	Mean	5%	95%
ι	Uniform(0,100)	2.8233	2.8144	2.8360
ϕ	Uniform(0,100)	0.3036	0.2697	0.3217
γ_0	Uniform(0,1000)	89.0076	73.2143	108.1845
γ_1	Uniform(0,1000)	1.9676	0.0892	5.8921
$\rho_a(0)$	Uniform(0,1)	0.8134	0.7208	0.8843
$\rho_a(1)$	Uniform(0,1)	0.7746	0.5543	0.8968
$\rho_p(0)$	Uniform(0,1)	0.9637	0.9340	0.9876
$\rho_p(1)$	Uniform(0,1)	0.9260	0.8258	0.9941
$\rho_\kappa(0)$	Uniform(0,1)	0.6656	0.4152	0.8946
$\rho_\kappa(1)$	Uniform(0,1)	0.7804	0.6728	0.8872
$a^*(1)$	Uniform(-10,0)	-0.0059	-0.0072	-0.0047
$p^*(1)$	Uniform(0,10)	0.0005	0.0000	0.0013
$\kappa^*(1)$	Uniform(0,1)	0.2305	0.2203	0.2440

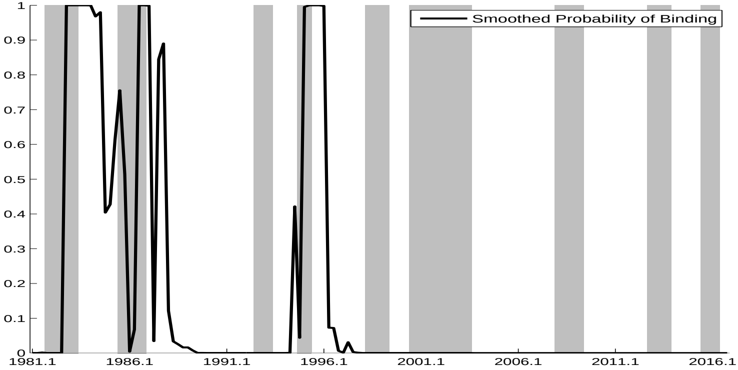
Posterior of Logistic Function



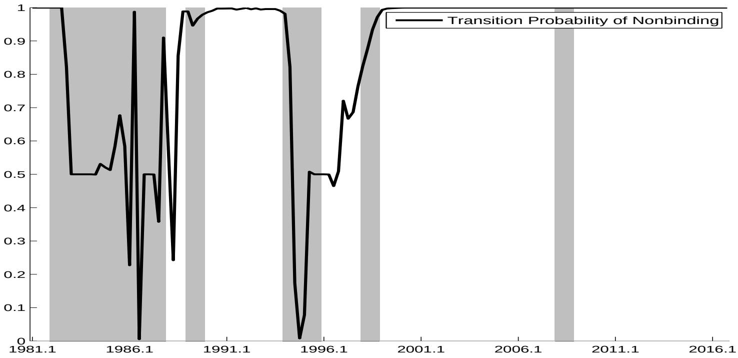
Crises Estimates vs. Reinhart-Rogoff Currency Crisis Dates



Crises Estimates vs. OECD Recession Dates



Transition Prob. vs. Reinhart-Rogoff Currency Crisis Dates



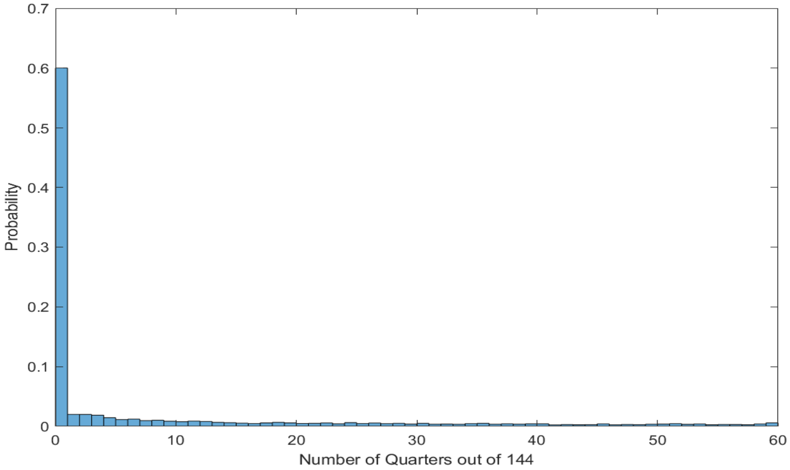
Estimation Results: Shock Standard Deviations

Parameter	Prior	Mean	5%	95%
$\sigma_r(0)$	Uniform(0,1)	0.0007	0.0001	0.0015
$\sigma_r(1)$	Uniform(0,1)	0.0438	0.0332	0.0496
$\sigma_a(0)$	Uniform(0,1)	0.0056	0.0043	0.0068
$\sigma_a(1)$	Uniform(0,1)	0.0091	0.0062	0.0123
$\sigma_p(0)$	Uniform(0,1)	0.0401	0.0338	0.0478
$\sigma_p(1)$	Uniform(0,1)	0.0487	0.0218	0.0766
$\sigma_\kappa(0)$	Uniform(0,1)	0.0012	0.0001	0.0030
$\sigma_\kappa(1)$	Uniform(0,1)	0.0248	0.0072	0.0419

Variance Decomposition

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

Crisis Frequency



What Drives the Crisis Frequency?

Shock		Mean	70%	90%
All Shocks		10.99	13	44
Individual				
Interest Rate Only	$\varepsilon_{r,t}$	0.01	0	0
Technology Only	$\varepsilon_{a,t}$	2.07	0	7
Import Price Only	$\varepsilon_{p,t}$	4.81	4	17
Leverage Only	$\varepsilon_{\kappa,t}$	3.26	0	0

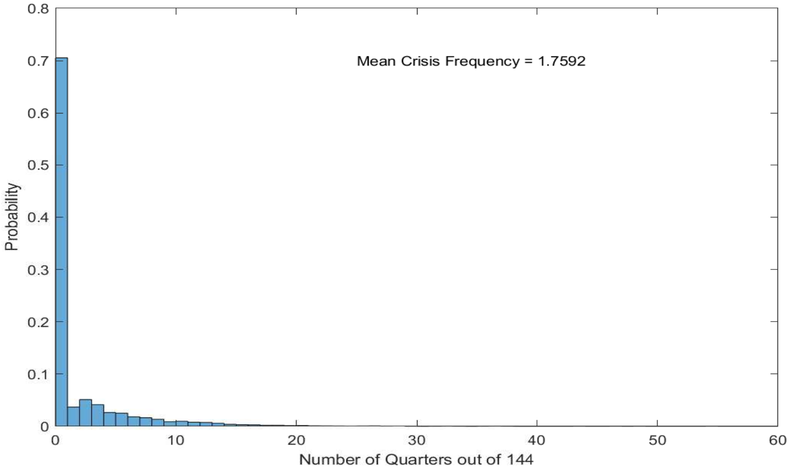
The Research Agenda: Capital Controls and Crises

- Would Different Capital Control Policies help Avoid or Mitigate Crises?
- Given Estimated Shocks and Frictions, Regenerate Data with Counterfactual Policy
- Consider Specific Rules or Find Optimal Rules
- Example: Tax on Debt that is Returned Lump-Sum

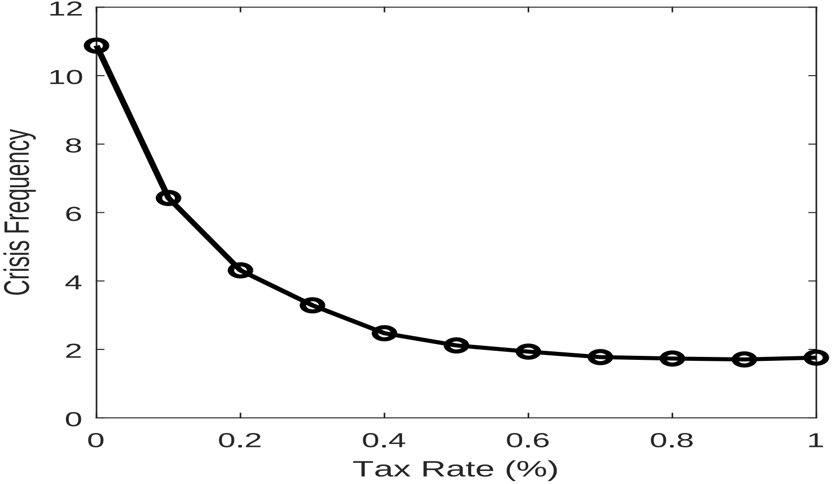
$$T_t = \tau_t^B B_t$$

- Outstanding Issue: What about Observed Crises?

Crisis Frequency with 1% Tax



Crisis Frequency with Various Tax Rates



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