International Reserves, Risk Tolerance, and Crisis Risk

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Predicting Crises is Important, yet Inglorious

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What Good Are Economists Anyway?

- Why they failed to predict the global economic crisisand why their help is still crucial to a recovery

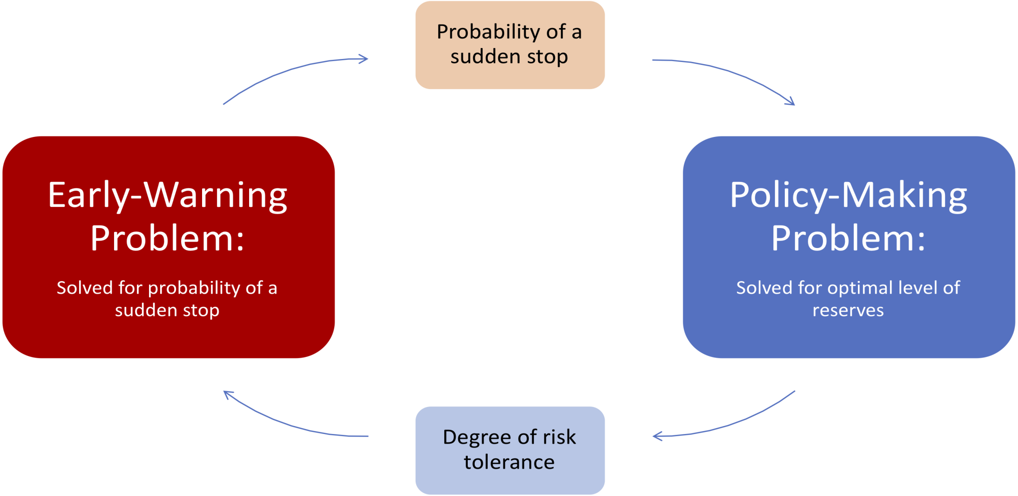
Early-Warning Models to Predict Crises

- Since Mexican crisis, early-warning models have been developed
  - Use a set of indicators X to forecast crisis risk $\pi(X)$
  - Aim to catalyze policy actions for crisis prevention and mitigation
- **Early-warning problem and policy-making problem are interconnected**
  - Yet ignored in the literature following Kaminsky et al. (1998)

Research Objective

- Research question
  - How to embed early-warning problem into policy-making problem?
- Propose a two-stage framework
  - First stage: early-warning problem is solved for crisis risk
  - Second stage: policy-making problem is solved for optimal policy action
- Provide empirical implications
  - Explain the buildup of international reserves in emerging markets
  - Conduct counterfactual analysis on level of reserves

A Two-Stage Framework



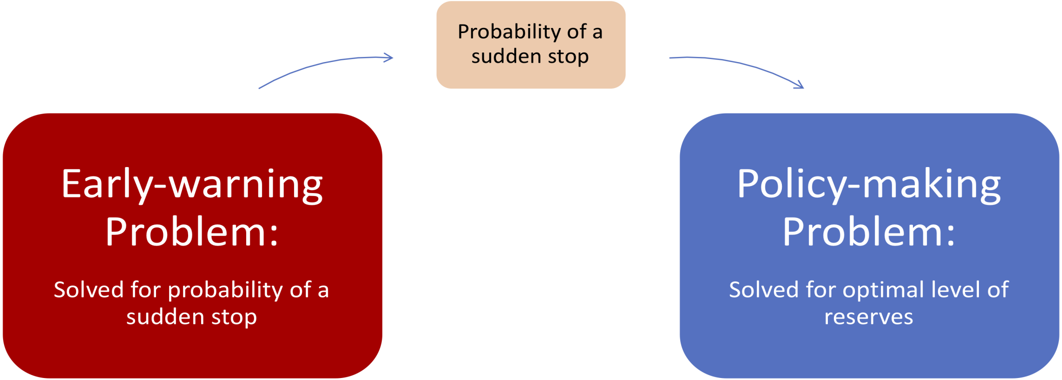
Road Map

- Literature
- A Two-Stage Problem
- Implementation Method
- Estimation and Performance
- Empirical Implications
- Conclusion

Literature

- Welfare-based trade-off of international reserves holdings e.g. Aizenman & Lee (2007), Durdu et al. (2009), Alfaro & Kanczuk (2009), Jeanne & Ranciere (2011)
  - This paper sheds light on suboptimality of policy decisions caused by imperfect crisis risk estimates
- Early-warning models e.g. Kaminsky et al. (1998), Alessi & Detken (2011)
  - This paper bridges the gap between policy objective and econometrics specification
  - Shows structurally welfare-based error asymmetry between false alarms and missed crises
- Reserves adequacy e.g. Jeanne & Ranciere (2011), Bianchi et al. (2016)
  - This paper presents empirical evidence of time-varying risk tolerance of policymakers
  - Provides a new perspective to explain the buildup of reserves in emerging countries

From Early-Warning to Policy-Making



A Welfare-Maximizing Problem for Reserves

- An insurance framework developed by Jeanne and Ranciere (2011)
  - Non-crisis periods: Government pays a premium X
  - Sudden stops: Government receives a payment R
  - Can be replicated by issuing perpetuity in a dynamic framework

- Given the probability of a sudden stop, $\{X, R\}$ solves

$$
\begin{aligned}
&\max_{\{X,\ R\}} \pi_t u(C_t^s) + (1-\pi_t)u(C_t^n) \\
\text{s.t.} \quad & C_t^n = Y_t^n + L_t - (1+r)L_{t-1} - X_t \\
& C_t^s = (1-\gamma)Y_t^n - (1+r)L_{t-1} + R_t - X_t \\
& L_t = \lambda Y_t^n \\
& Y_{t+1}^n = (1+g)Y_t^n \\
& X_t = \frac{\bar{\pi}}{\bar{\pi} + p(1-\bar{\pi})} R_t
\end{aligned}
$$

γ: output loss in a sudden stop; λ: size of a sudden stop p: the relative price of a non-crisis dollar in terms of a crisis dollar; g: the growth rate; r: risk-free rate

Welfare Derived from Risk Estimate

- Optimal insurance contract payment $(X, R) = (X(\pi), R(\pi))$, and level of reserves-to-GDP ratio $\rho \equiv R/Y^n = \rho(\pi)$

- π is not observable: policymakers have to estimate the probability of a sudden stop and then choose the contract payment based on the estimate $\hat{\pi} \Rightarrow (X, R) = (X(\hat{\pi}), R(\hat{\pi}))$

- Let $\bar{U}^{\text{real}}(\pi, \hat{\pi})$ be the expected real welfare derived from $(X(\hat{\pi}), R(\hat{\pi}))$,

$$\bar{U}^{\text{real}}(\underbrace{\pi}_{\substack{\textit{the true probability over} \\ \textit{which welfare is averaged}}}, \underbrace{\hat{\pi}}_{\substack{\textit{the estimated probability on} \\ \textit{which reserves are calculated}}})$$

$$= \pi U\left(\frac{C^s((X(\hat{\pi}), R(\hat{\pi})))}{Y^n}\right) + (1 - \pi) U\left(\frac{C^n((X(\hat{\pi}), R(\hat{\pi})))}{Y^n}\right)$$

Welfare Cost Incurred by Imperfect Risk Estimate

Lemma 1.

The insurance contract payment $(X(\hat{\pi}), R(\hat{\pi}))$ based on any estimated sudden stop risk $\hat{\pi}$ is not optimal under the true risk π, unless $\hat{\pi} = \pi$.

Hence, welfare cost of any risk estimate $\hat{\pi}$ under true risk π is defined as $\bar{U}^{\text{real}}(\pi, \pi) - \bar{U}^{\text{real}}(\pi, \hat{\pi})$

$$\begin{aligned}\bar{U}^{\text{real}}(\pi, \pi) - \bar{U}^{\text{real}}(\pi, \hat{\pi}) = {} & \pi U\Big(\frac{C^s((X(\pi), R(\hat{\pi})))}{Y^n}\Big) + (1-\pi) U\Big(\frac{C^n((X(\pi), R(\pi)))}{Y^n}\Big) \\ & - \pi U\Big(\frac{C^s((X(\hat{\pi}), R(\hat{\pi})))}{Y^n}\Big) + (1-\pi) U\Big(\frac{C^n((X(\hat{\pi}), R(\hat{\pi})))}{Y^n}\Big) \geq 0.\end{aligned}$$

Welfare-Based Objective Function

- Define a *Welfare Loss* denoted by $L_W(\hat{\pi}, \pi)$, as the welfare costs of a probability estimate $\hat{\pi}$ under true probability π

$$L_{\mathrm{W}}(\hat{\pi}, \pi) = \bar{U}^{\mathrm{real}}(\pi, \pi) - \bar{U}^{\mathrm{real}}(\pi, \hat{\pi})$$

- The objective function is thereby $\mathbb{E}\left[L_{\mathrm{W}}(\hat{\pi}, \pi)\right]$

- Rewrite as a binary classification problem

Binary Classification Problem

- Let y and $\hat{y}$ denote the true binary crisis realization and the predicted binary crisis flag respectively, both taking 1 to indicate crisis and 0 to indicate non-crisis
- Mapping:
  - $\pi(X) = \mathbb{P}(y = 1|X)$
  - $\hat{y} = \mathbb{1}(\hat{\pi} > c)$ for some optimal threshold c
- Outcome matrix

		True realizations: non-crisis	True realizations: crisis
Predicted flags	non-crisis	True negative ($\hat{y} = 0$ & $y = 0$)	Missed crisis ($\hat{y} = 0$ & $y = 1$)
	crisis	False alarm ($\hat{y} = 1$ & $y = 0$)	True positive ($\hat{y} = 1$ & $y = 1$)

Asymmetric Welfare-Based Errors

- Written as a binary classification problem, the objective function to minimize

$$\omega_{FA} \cdot \underbrace{\mathbb{P}(\hat{y} = 1 | y = 0)}_{\text{the percentage of false alarms}} + \omega_{MC} \cdot \underbrace{\mathbb{P}(\hat{y} = 0 | y = 1)}_{\text{the percentage of missed crises}}$$

Proposition 1.

Welfare-based weight on the percentage of missed crises is larger than that on the percentage of false alarms, as long as consumers are risk averse. That is

$$\omega_{MC} > \omega_{FA}$$

if $u(c) = \frac{c^{1-\sigma}-1}{1-\sigma}$ and $\sigma > 0$.

- However, the literature following Kaminsky et al. (1998) ignores the welfare-based adjustment and uses $\mathbb{P}(\hat{y} = 1 | y = 0) + \mathbb{P}(\hat{y} = 0 | y = 1)$

Implementation: Neyman-Pearson Paradigm

- Neyman-Pearson paradigm (Cannon et al., 2002) characterizes the objective function as

$$\textbf{min } \mathbb{P}(\hat{y} = 1 | y = 0)$$
$$\textbf{s.t. } \mathbb{P}(\hat{y} = 0 | y = 1) < \alpha$$

Proposition 2.

Solving the objective function under Neyman-Pearson paradigm with $\alpha < 0.5$ is equivalent to minimize an objective function characterized as $\omega_{FA} \cdot \mathbb{P}(\hat{y} = 1 | y = 0) + \omega_{MC} \cdot \mathbb{P}(\hat{y} = 0 | y = 1)$ with some $\omega_{MC} > \omega_{FA}$.

A Good Fit for Early-Warning Problem

- Model uncertainty: no agreement on a workhorse model of crises makes it impossible to pin down exact welfare costs
  - Complexity and interaction of many variables
  - Infrequent but large global regime shifts

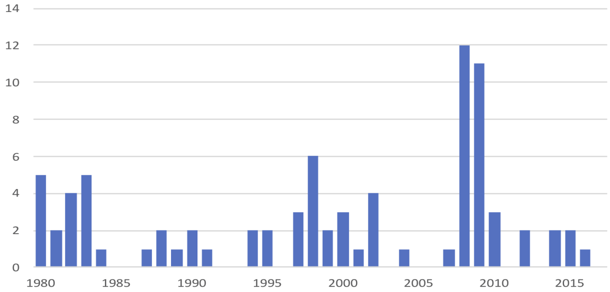
- Interpretability: upper bound on percentage of missed crises can be
  - Set as forecasting goal by policymakers
  - Modeled as risk tolerance by researchers

- Robustness: control on percentage of missed crises achieved on **population level** by Tong et al. (2018)
  - Critical in forecasting

An Application to Predicting Sudden Stops

Crisis Definition

- Basu et al. (2019): Sudden stops in net private capital inflows
    - Net private capital inflows in year t (as % of GDP in year t-1) at least 2 percentage pts lower than that in t-1 and t-2
    - Or IMF programs > 500% of quota to capture counterfactual
- With growth impacts
    - In year t or t+1, deviation of growth from 5-year trend in lower 10th percentile
    - Or IMF programs > 500% of quota in year t+1 to capture counterfactual
- 53 EMs in 1980-2017: 82 sudden stops with growth impacts (4.1% of sample)



Explanatory Indicators

- Principle: capture different generations of theoretical models

First generation
- Fiscal balance (% of GDP)
- 5-year change in M2/GDP
- Reserves/M2 and Reserves/GDP
- Dummies for hard peg and float
- Dummy for parallel market

Second generation
- Change in unemployment rate
- Real GDP growth

Third generation: Flows and mismatch
- Share of non-investment grade debt
- Current account balance/GDP
- Amortization
- FX share of public debt
- Debt service/exports
- FX share of household and non- financial corporate credit

Political shocks
- Political violence
- Successful coup

Third generation: Debt shocks
- External debt/GDP
- External debt/exports
- Private external debt/GDP
- Bank external debt/GDP
- Cross-border bank-to-bank liabilities/GDP
- Non-bank private external debt/GDP
- Total and external Public debt/GDP
- Private credit/GDP
- Household liabilities/GDP
- Foreign liabilities/Domestic credit

Third generation: Buffers
- EMBI spread (level and growth)
- Corporate sector returns
- Default probability
- Interest coverage ratio
- Price-earnings ratio
- Bank returns
- Share of non-performing loans
- Banks' capital-asset ratio
- Loan-to-deposit ratio
- Primary gap/GDP
- Inflation

Third generation: Bursting bubbles
- Q2-to-Q4 change in NEER
- REER acceleration
- Real house price acceleration
- Real stock price acceleration
- Changes in all debt/GDP in debt shocks

Third generation: Global shocks
- FFR (level and growth)
- VIX
- US NEER change
- US yield spread
- TED spread

Law of one price
- 5-year cumulative inflation

Third generation: Medium-term (5-yr) building bubbles
- Private sector credit growth
- Housing price growth
- Stock price growth
- REER growth
- Cross-border bank-to-bank liabilities to GDP growth
- External debt/GDP growth
- Contribution of finance to GDP
- Contribution of construction to GDP

Current account shocks
- Real growth in exports
- % change in ToT
- % change in non-fuel commodity TOT
- Absolute oil balance/GDP
- % change in oil price

Contagion
- Change in export partner growth relative to 5-year trend
- Bank-to-bank Liabilities to AEs with financial crisis/GDP
- Frequency of banking crises in AEs
- Similarity to last year's crises

Signal-Extraction Model

- Signal-extraction model proposed by Kaminsky et al. (1998)
  - Best performed
  - Not data-hungry
  - Implemented for decades

- For each variable Z and a threshold Z^c
  - 1 is given when $Z > Z^c$
  - 0 is given when $Z \leq Z^c$

- Optimal threshold is chosen to minimize any given objective function

- All flags are aggregated across variables to yield an overall risk index using weights that are inverse of the attained minimum of objective function

Compare Two Objective Functions

	Literature	Neyman-Pearson paradigm
Objective function	$\mathbb{P}(\hat{y}=1\|y=0)+\mathbb{P}(\hat{y}=0\|y=1)$	$\mathbb{P}(\hat{y}=1\|y=0)$ **s.t.** $\mathbb{P}(\hat{y}=0\|y=1)<\alpha$
Threshold	**augmin** $\mathbb{P}(\hat{y}=1\|y=0)+\mathbb{P}(\hat{y}=0\|y=1)$	**augmin** $\mathbb{P}(\hat{y}=1\|y=0)$ **s.t.** $\mathbb{P}(\hat{y}=0\|y=1)<\alpha$
Weight	$\frac{1}{\mathbb{P}(\hat{y}=1\|y=0)+\mathbb{P}(\hat{y}=0\|y=1)}$	$\frac{1}{\mathbb{P}(\hat{y}=1\|y=0)}$

- 24-month forecasting horizon
  - Use data up to end of year t to forecast crisis risk in year $t+2$
- Evaluation: replicate real-time forecasting practice
  - Estimate a model using data up to year t and then apply it to data in next two years

NP Delivers Better Prediction Performance

- Sum of errors: $\mathbb{P}(\hat{y} = 1|y = 0) + \mathbb{P}(\hat{y} = 0|y = 1)$
- Neyman-Pearson paradigm will deliver even better prediction performance with respect to welfare-maximizing criterion

A. Literature			
Year	Missed crises (%)	False alarms (%)	Sum of errors (%)
2007	30	20	50
2009	**100**	25	**125**
2011	**100**	17	**117**
Mean	77	21	**98**
B. Neyman-Pearson paradigm with $\alpha = 0.4$			
Year	Missed crises (%)	False alarms (%)	Sum of errors (%)
2007	17	63	80
2009	0	64	**64**
2011	25	51	**76**
Mean	14	59	**73**

From Policy-Making to Early-Warning

Early-warning Problem:

Solved for probability of a sudden stop

Policy-making Problem:

Solved for optimal level of reserves

Degree of risk tolerance

Risk Tolerance Modeled by NP

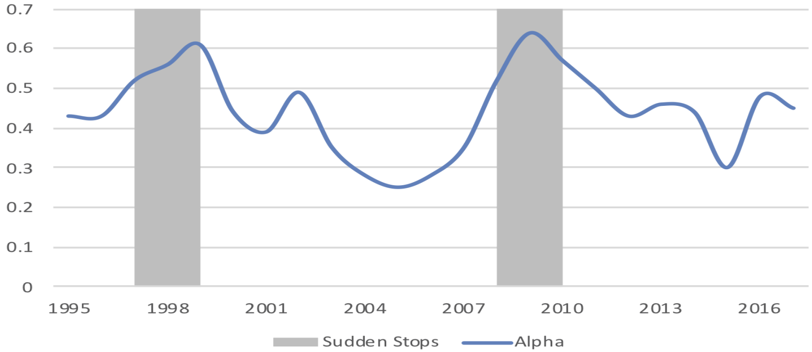
- Measure risk tolerance of policymakers by their control on percentage of missed crises (α): $\alpha \Uparrow$, risk tolerance $\Uparrow$

- Calibration procedure: $\alpha \Rightarrow \hat{\pi} \Rightarrow \rho(\hat{\pi}, \lambda, \gamma, g, \bar{\pi}, \delta)$
  - Use data up to year t to forecast crisis risk in year $t + 2$
  - Reserves accumulated in year $t + 1$ is to insure against crisis risk in year $t + 2$
  - Hence, α in year t is calibrated to match reserves level in year $t + 1$

- Other parameters are calibrated with reference to historical data up to year t
  - country's own history: size of sudden stops (λ), output loss (γ), potential output growth (g), unconditional probability of a sudden stop ($\bar{\pi}$)
  - global history: term premium (δ)

Time-Varying Risk Tolerance

- Higher risk tolerance precedes two major waves of sudden stops: Asian financial crises and global financial crises
- Explanation: high risk tolerance $\Rightarrow$ low crisis risk estimates $\Rightarrow$ level of reserves too low to prevent real consequences



Counterfactual: Asian Financial Crises

- What if lower risk tolerance was imposed before Asian financial crises?
  - Choose alternative $\alpha = 0.4$
- Reserves-to-GDP: 11.5% $\Rightarrow$ 19.5%
- Competition from US, credit growth and hot money would be more predictive, while CA and TED spread were less predictive

Variable	Change
Export Partner Growth	$5^{th} \Uparrow 2^{nd}$
5yr Broad Money Growth	$7^{th} \Uparrow 4^{th}$
5yr External Debt Growth	$9^{th} \Uparrow 6^{th}$
Current Account Balance	$1^{st} \Downarrow 8^{th}$
TED Spread	$4^{th} \Downarrow 10^{th}$
Reserves-to-GDP	11.5% $\Uparrow$ 19.5%

Counterfactual: Global Financial Crises

- What if lower risk tolerance was imposed before global financial crises?
  - Choose alternative $\alpha = 0.4$
- Reserves-to-GDP: 21.3% $\Rightarrow$ 38.5%
- Change in global financing condition would be more predictive, while domestic credit growth was less predictive

Variable	Rank
US Term Premium	$7^{th} \Uparrow 1^{st}$
Current Account Balance	$6^{th} \Uparrow 2^{nd}$
Fed Rate Change	$10^{th} \Uparrow 3^{rd}$
Private Credit Growth	$1^{st} \Downarrow 6^{th}$
5yr Private Credit Growth	$2^{nd} \Downarrow 9^{th}$
Reserves-to-GDP	21.3% $\Uparrow$ 38.5%

Conclusion

- Building upon a two-stage framework
  - Suboptimality of policy decisions caused by imperfect crisis risk estimates
  - Welfare-cost asymmetry between false alarms and missed crises
- Bringing in new paradigm
  - Better prediction performance with respect to werlfare-maximizing criterion
  - Time-varying risk tolerance of polcymakers accounting for reserves buildup
- Policy implication: commitment mechanism

Thank you!