International Reserves, Risk Tolerance, and Crisis Risk

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The views expressed in this presentation are those of the authors and do not necessarily represent the views of the IMF, its Executive Board, or IMF management.
What Good Are Economists Anyway?

- Why they failed to predict the global economic crisis and 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

Early-Warning Problem:
Solved for probability of a sudden stop

Probability of a sudden stop

Degree of risk tolerance

Policy-Making Problem:
Solved for optimal level of reserves
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

Early-warning Problem:
Solved for probability of a sudden stop

Probability of a sudden stop

Policy-making Problem:
Solved for optimal level of reserves
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

$$\max_{\{X, R\}} \pi_t u(C^s_t) + (1 - \pi_t) u(C^n_t)$$

s.t.

$$C^n_t = Y^n_t + L_t - (1 + r)L_{t-1} - X_t$$
$$C^s_t = (1 - \gamma)Y^n_t - (1 + r)L_{t-1} + R_t - X_t$$
$$L_t = \lambda Y^n_t$$
$$Y^n_{t+1} = (1 + g)Y^n_t$$
$$X_t = \frac{\bar{\pi}}{\bar{\pi} + p(1 - \bar{\pi})} R_t$$

$\gamma$: output loss in a sudden stop; $\lambda$: 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 \( \rho \equiv R/Y^n = \rho(\pi) \)

- \( \pi \) 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 \( (X(\hat{\pi}), R(\hat{\pi})) \),

\[
\bar{U}^{\text{real}}(\underline{\pi}, \hat{\pi}) = \pi U\left(\frac{C^s((X(\hat{\pi}), R(\hat{\pi})))}{Y^n}\right) + (1 - \pi) U\left(\frac{C^n((X(\hat{\pi}), R(\hat{\pi})))}{Y^n}\right)
\]

\(\underline{\pi}\) is the true probability over which welfare is averaged, and \(\hat{\pi}\) is the estimated probability on which reserves are calculated.
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 \(\pi\), unless \(\hat{\pi} = \pi\).

Hence, welfare cost of any risk estimate \(\hat{\pi}\) under true risk \(\pi\) is defined as

\[
\tilde{U}^{\text{real}}(\pi, \pi) - \tilde{U}^{\text{real}}(\pi, \hat{\pi})
\]

\[
= \pi U\left(\frac{C^s((X(\pi), R(\pi)))}{Y_n}\right) + (1 - \pi) U\left(\frac{C^n((X(\pi), R(\pi)))}{Y_n}\right)
\]

\[
- \pi U\left(\frac{C^s((X(\hat{\pi}), R(\hat{\pi}))}{Y_n}\right) + (1 - \pi) U\left(\frac{C^n((X(\hat{\pi}), R(\hat{\pi}))}{Y_n}\right) \geq 0.
\]
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 $\pi$

$$L_W(\hat{\pi}, \pi) = \bar{U}_{\text{real}}(\pi, \pi) - \bar{U}_{\text{real}}(\pi, \hat{\pi})$$

• The objective function is thereby $\mathbb{E}[L_W(\hat{\pi}, \pi)]$

• 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:
  
  $\pi(X) = P(y = 1|X)$
  $\hat{y} = 1(\hat{\pi} > c)$ for some optimal threshold $c$

• Outcome matrix

<table>
<thead>
<tr>
<th>Predicted flags</th>
<th>non-crisis</th>
<th>crisis</th>
</tr>
</thead>
<tbody>
<tr>
<td>non-crisis</td>
<td>True negative ($\hat{y} = 0 &amp; y = 0$)</td>
<td>Missed crisis ($\hat{y} = 0 &amp; y = 1$)</td>
</tr>
<tr>
<td>crisis</td>
<td>False alarm ($\hat{y} = 1 &amp; y = 0$)</td>
<td>True positive ($\hat{y} = 1 &amp; y = 1$)</td>
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</table>
Asymmetric Welfare-Based Errors

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

\[ \omega_{FA} \cdot \mathbb{P} (\hat{y} = 1 | y = 0) + \omega_{MC} \cdot \mathbb{P} (\hat{y} = 0 | y = 1) \]

the percentage of false alarms 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 \( \mathbb{P} (\hat{y} = 1 | y = 0) + \mathbb{P} (\hat{y} = 0 | y = 1) \)
Neyman-Pearson paradigm (Cannon et al., 2002) characterizes the objective function as

$$\min \mathbb{P}(\hat{y} = 1|y = 0)$$

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

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

<table>
<thead>
<tr>
<th>First generation</th>
<th>Third generation: Debt shocks</th>
<th>Third generation: Bursting bubbles</th>
<th>Third generation: Medium-term (5-yr) building bubbles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiscal balance (% of GDP)</td>
<td>External debt/GDP</td>
<td>Q2-to-Q4 change in NEER</td>
<td>Private sector credit growth</td>
</tr>
<tr>
<td>5-year change in M2/GDP</td>
<td>External debt/exports</td>
<td>REER acceleration</td>
<td>Housing price growth</td>
</tr>
<tr>
<td>Reserves/M2 and Reserves/GDP</td>
<td>Private external debt/GDP</td>
<td>Real house price acceleration</td>
<td>Stock price growth</td>
</tr>
<tr>
<td>Dummies for hard peg and float</td>
<td>Bank external debt/GDP</td>
<td>Real stock price acceleration</td>
<td>REER growth</td>
</tr>
<tr>
<td>Dummy for parallel market</td>
<td>Cross-border bank-to-bank liabilities/GDP</td>
<td>Changes in all debt/GDP in debt shocks</td>
<td>Cross-border bank-to-bank liabilities to GDP growth</td>
</tr>
<tr>
<td></td>
<td>Non-bank private external debt/GDP</td>
<td></td>
<td>External debt/GDP growth</td>
</tr>
<tr>
<td></td>
<td>Total and external Public debt/GDP</td>
<td></td>
<td>Contribution of finance to GDP</td>
</tr>
<tr>
<td></td>
<td>Private credit/GDP</td>
<td></td>
<td>Contribution of construction to GDP</td>
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<tr>
<td></td>
<td>Household liabilities/GDP</td>
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<td></td>
<td>Foreign liabilities/Domestic credit</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Third generation: Flows and mismatch</th>
<th>Third generation: Global shocks</th>
<th>Third generation: Buffers</th>
<th>Current account shocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Share of non-investment grade debt</td>
<td>FFR (level and growth)</td>
<td>EMBI spread (level and growth)</td>
<td>Real growth in exports</td>
</tr>
<tr>
<td>Current account balance/GDP</td>
<td>VIX</td>
<td>Corporate sector returns</td>
<td>% change in exports</td>
</tr>
<tr>
<td>Amortization</td>
<td>US NEER change</td>
<td>Default probability</td>
<td>% change in ToT</td>
</tr>
<tr>
<td>FX share of public debt</td>
<td>US yield spread</td>
<td>Interest coverage ratio</td>
<td>% change in non-fuel commodity TOT</td>
</tr>
<tr>
<td>Debt service/exports</td>
<td>TED spread</td>
<td>Price-earnings ratio</td>
<td>Absolute oil balance/GDP</td>
</tr>
<tr>
<td>FX share of household and non-financial corporate credit</td>
<td></td>
<td>Bank returns</td>
<td>% change in oil price</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>Political shocks</th>
<th>Law of one price</th>
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</thead>
<tbody>
<tr>
<td>Political violence</td>
<td>5-year cumulative inflation</td>
</tr>
<tr>
<td>Successful coup</td>
<td></td>
</tr>
</tbody>
</table>

**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

<table>
<thead>
<tr>
<th></th>
<th>Literature</th>
<th>Neyman-Pearson paradigm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objective function</strong></td>
<td>$\mathbb{P}(\hat{y} = 1</td>
<td>y = 0) + \mathbb{P}(\hat{y} = 0</td>
</tr>
<tr>
<td></td>
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<tr>
<td><strong>Threshold</strong></td>
<td>augmin $\mathbb{P}(\hat{y} = 1</td>
<td>y = 0) + \mathbb{P}(\hat{y} = 0</td>
</tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>$\frac{1}{\mathbb{P}(\hat{y}=1</td>
<td>y=0)+\mathbb{P}(\hat{y}=0</td>
</tr>
</tbody>
</table>

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

### A. Literature

<table>
<thead>
<tr>
<th>Year</th>
<th>Missed crises (%)</th>
<th>False alarms (%)</th>
<th>Sum of errors (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>30</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>2009</td>
<td>100</td>
<td>25</td>
<td>125</td>
</tr>
<tr>
<td>2011</td>
<td>100</td>
<td>17</td>
<td>117</td>
</tr>
<tr>
<td>Mean</td>
<td>77</td>
<td>21</td>
<td>98</td>
</tr>
</tbody>
</table>

### B. Neyman-Pearson paradigm with $\alpha = 0.4$

<table>
<thead>
<tr>
<th>Year</th>
<th>Missed crises (%)</th>
<th>False alarms (%)</th>
<th>Sum of errors (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>17</td>
<td>63</td>
<td>80</td>
</tr>
<tr>
<td>2009</td>
<td>0</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td>2011</td>
<td>25</td>
<td>51</td>
<td>76</td>
</tr>
<tr>
<td>Mean</td>
<td>14</td>
<td>59</td>
<td>73</td>
</tr>
</tbody>
</table>
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
• Measure risk tolerance of policymakers by their control on percentage of missed crises ($\alpha$):
  $\alpha \uparrow$, 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, $\alpha$ 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 ($\lambda$), output loss ($\gamma$), potential output growth ($g$), unconditional probability of a sudden stop ($\bar{\pi}$)
  ○ global history: term premium ($\delta$)
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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Export Partner Growth</td>
<td>$5^{th}$ $\uparrow$ $2^{nd}$</td>
</tr>
<tr>
<td>5yr Broad Money Growth</td>
<td>$7^{th}$ $\uparrow$ $4^{th}$</td>
</tr>
<tr>
<td>5yr External Debt Growth</td>
<td>$9^{th}$ $\uparrow$ $6^{th}$</td>
</tr>
<tr>
<td>Current Account Balance</td>
<td>$1^{st}$ $\downarrow$ $8^{th}$</td>
</tr>
<tr>
<td>TED Spread</td>
<td>$4^{th}$ $\downarrow$ $10^{th}$</td>
</tr>
<tr>
<td>Reserves-to-GDP</td>
<td>11.5% $\uparrow$ 19.5%</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>US Term Premium</td>
<td>7&lt;sup&gt;th&lt;/sup&gt; $\uparrow$ 1&lt;sup&gt;st&lt;/sup&gt;</td>
</tr>
<tr>
<td>Current Account Balance</td>
<td>6&lt;sup&gt;th&lt;/sup&gt; $\uparrow$ 2&lt;sup&gt;nd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fed Rate Change</td>
<td>10&lt;sup&gt;th&lt;/sup&gt; $\uparrow$ 3&lt;sup&gt;rd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Private Credit Growth</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; $\downarrow$ 6&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>5yr Private Credit Growth</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; $\downarrow$ 9&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>Reserves-to-GDP</td>
<td>21.3% $\uparrow$ 38.5%</td>
</tr>
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</table>
**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 welfare-maximizing criterion
  - Time-varying risk tolerance of policymakers accounting for reserves buildup

- **Policy implication:** commitment mechanism
Thank you!