A Primer on Quantitative Models of Sovereign Default on External Debt
Argentina: Default risk & business cycles

- **Spread**
- **GDP (right axis)**
- **Consumption (right axis)**

The graph shows the trend of spread, GDP, and consumption from 1983Q2 to 2004Q2.
Greece: Default risk & Business Cycles

a) Ten-year government bond yields

b) Quarterly real GDP growth (annual rate)
External default in the literature

• Heavily studied in the 1980s in the aftermath of defaults by many developing countries (LA, Asia, Africa)
• Most work was theoretical, non-structural empirical, or narrative.
• Main contribution was Eaton and Gerzovitz (1981): first model of strategic default by benevolent gov. issuing debt without collateral
• E&G showed there can be eq. with debt subject to default risk when gov. is unable to commit to repay risk-neutral foreign lenders:
  – Two default costs: Exclusion, Fixed loss of consumption
  – Debt is NSC, income is exogenous and stochastic, gov. compares every period value of repayment v. autarky, and defaults if latter is higher
  – Prob. of default at t+1 on debt sold at t is given by the prob. that at the given debt the income lands at t+1 at a value in which default is optimal
  – Risk-neutral pricing implies a default risk premium given by default prob.
  – Followed by large theoretical literature exploring other angles (notably Bulow & Rogoff showed the model needs full exclusion)
• Topic faded away until mid 2000s, motivated by EMs defaults (Argentina, Russia, Ecuador) and role of risk premia in cycles, and more recently by European crisis. New focus on quantitative work.
Explaining the link between country risk & the real economy

- **RBC models w. working capital and exogenous country risk:**
  - Observed country risk as exogenous int. rate shock
  - Labor paid in advance, int. rate shocks affect wage costs
  - If all labor is paid in advance and int. rate shocks are large, country risk has large real effects
  - Caveats: country risk is not exogenous, and working capital financing is likely to be much smaller than in these models

- **EG Models of strategic default with exogenous output:**
  - Arellano (2008), Aguiar & Gopinath (2006), Yue (2006), Bi (2008a,b), Chatterjee & Eyigungor (2012), D’Erasmo (2008), Cuadra & Sapriza (2008), Hatchondo et al (2008), Wright (2008), Benjamin and Wright (2009), Pitchford & Wright (2010), etc...
  - Quantitative studies of variants of Eaton-Gersovitz model
  - Calibrated to output process of defaulting economies (Argentina)
  - Can’t explain observed default probs. and debt ratios unless particular form of output costs are imposed exogenously

- **Default models with endogenous output and private sector role (Mendoza & Yue (2012), Sosa-Padilla (2015), Arellano et al. (2016))**
• Benevolent government maximizes private utility:
\[ E_0 \sum_{t=0}^{\infty} \beta^t u(c_t), \]

• World credit market: NSC discount bonds \( B' \) with endogenous pricing function \( q(B', y) \). A debt contract means \( B' < 0 \), so the economy gets \(-q(B', y)B'\) today and pays \( B' \) tomorrow if it does not default.

• Budget constraint if no default:
\[ c = y + B - q(B', y)B'. \]

• Budget constraint if default:
\[ c = y^{def}, \quad y^{def} = h(y) \leq y \quad \text{with } h'(y) > 0 \]

• Risk-neutral creditors max. profits given prices and default prob. \( \delta \):

Profits: \( \phi = qB' - \frac{(1 - \delta)}{1 + r} B' \)

Optimality cond: \( q = \frac{(1 - \delta)}{1 + r} \)
Recursive formulation

- Government and lenders act sequentially.
  - Gov. starts with $B$, observes $y$, and chooses to default or not
  - If Gov repays, it observes a pricing function $q(B', y)$ and chooses $B'$ optimally, and creditors taking $q$ and $\delta$ as given choose $B'$

- At equilibrium the pricing functions for gov. & creditors match
  \[
  q(B', y) = \frac{(1 - \delta(B', y))}{1 + r}
  \]
  - For $B' \geq 0$, default prob. is zero and bonds pay world interest rate $1+r$
  - $q$ lies in the interval $[0, 1/(1+r)]$ and $1/q$ is country interest rate

- Value function for gov. with default option:
  \[
  v^o(B, y) = \max_{\{c, d\}} \{v^c(B, y), v^d(y)\}
  \]
  - “$c$” means value of continuation (staying in the credit contract)
  - “$d$” means value of default
Recursive formulation contn ‘d

- Value of default
  \[ v^d(y) = u(y^{def}) + \beta \int_{y'} \left[ \theta v^o(0, y') + (1 - \theta)v^d(y') \right] f(y', y)\,dy' \]
  - \( \theta \) is an exogenous probability of re-entry

- Value of continuation (conditional on not defaulting)
  \[ v^c(B, y) = \max_{y' \geq B} \left\{ u(y - q(B', y)B' + B) + \beta \int_{y'} v^o(B', y') f(y', y)\,dy' \right\} \]
  - subject to lower bound on debt \( B' > Z \)

- Repayment and default income sets (for given \( B \))
  \[ A(B) = \{ y \in Y : v^c(B, y) \geq v^d(y) \} \quad D(B) = \{ y \in Y : v^c(B, y) < v^d(y) \} \]
  - A default income threshold \( y^*(B) \) divides \( \{ y, B \} \) space into repayment & default regions
Recursive Equilibrium

- Recursive equilibrium is defined by (i) a consumption plan $c(s)$, for $s=\{B, y\}$, (ii) a policy function for sovereign debt $B'(s)$, (iii) repayment and default sets $A(B), D(B)$, and (iv) a bond pricing function $q(B', y)$ such that:
  a) Given (ii), $c(s)$ satisfies the budget constraint
  b) Given (iv), $B'(s), A(B)$ and $D(B)$ solve sovereign’s problem
  c) The pricing function $q(B', y)$ reflects default probabilities and satisfies the lenders’ arbitrage condition

- Resources generated by debt $-q(B', y)B'$ follow Laffer curve.
  - Default prob. rises as $B'$ falls because value of continuation is increasing in $B'$ and value of default is independent of B (Arellano proves using default & repayment sets, without differentiability)
  - Debt is inside $\underline{B} \leq B \leq 0$, because there is always a large (small) enough debt such that default (repayment) is optimal for all $y$
Default probability and default sets

- At equilibrium default probabilities and default sets satisfy:

\[ \delta(B', y) = \int_{D(B')} f(y', y) dy' \]

- If default set is empty, default probs are zero. If the default set includes all of \( Y \), default probs equal one. But in general:

Proposition 1. (Default sets are shrinking in assets.) For all \( B^1 \leq B^2 \), if default is optimal for \( B^2 \), in some states \( y \), then default will be optimal for \( B^1 \) for the same states \( y \), that is, \( D(B^2) \subseteq D(B^1) \).

- Akin to E+G proposition showing that default prob is increasing in debt.

- Given Prop. 1 and bounded support for \( y \), it follows that when bonds are sold with default risk they satisfy these boundaries:

\[ \underline{B} \leq \overline{B} \leq 0 \]

\[ \overline{B} = \sup \{ B : \quad D(B) = Y \} \]

\[ \underline{B} = \inf \{ B : \quad D(B) = \emptyset \} \]

- Note that this justifies that \( q(.) \) depends on both \( y \) and \( B \), but it only depends on \( y \) if the shock is not i.i.d. (E+G studied only iid)
Analytics of the i.i.d case

• Do govs. default in good times or bad times?
  – W. complete markets, incentives for default are higher in good times (when is time to repay or save)
  – W. incomplete markets it is possible to default in bad times

• In i.i.d. case, default incentives are stronger in bad times for sure:
  Proposition 3. Default incentives are stronger the lower the endowment. For all \( y_1 \leq y_2 \), if \( y_2 \in D(B) \), then \( y_1 \in D(B) \).
  – In bad times, contracts available are not useful insurance for a highly indebted borrower because they cannot increase \( c \) relative to \( y \), so default may be preferable in recessions.

• At equilibrium, debt provides resources according to a Laffer Curve:
  \[
  q(B')B' = \frac{1}{1 + r}[1 - F(y^*(B'))]B'
  \]
  – The default income threshold \( y^*(B) \) is decreasing in \( B \) due to Prop. 1.
  – At the threshold:
  \[
  v^d(y^*(B)) = v^c(B, y^*(B)) \text{ for } B \in (B, B)
  \]
For $B' < B^*$, the same consumption resources can be raised with higher $B'$ (smaller debt). Hence, risky debt exists only if risky borrowing region is non-empty.
Numerical application to Argentina

Table 1. Business Cycle Statistics for Argentina

<table>
<thead>
<tr>
<th>Default episode</th>
<th>$x$: Q1-2002</th>
<th>std($x$)</th>
<th>corr($x$, $y$)</th>
<th>corr($x$, $r_c$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest rates spread</td>
<td>28.60</td>
<td>5.58</td>
<td>-0.88</td>
<td></td>
</tr>
<tr>
<td>Trade balance</td>
<td>9.90</td>
<td>1.75</td>
<td>-0.64</td>
<td>0.70</td>
</tr>
<tr>
<td>Consumption</td>
<td>-16.01</td>
<td>8.59</td>
<td>0.98</td>
<td>-0.89</td>
</tr>
<tr>
<td>Output</td>
<td>-14.21</td>
<td>7.78</td>
<td>-0.88</td>
<td></td>
</tr>
</tbody>
</table>

$$u(c) = \frac{c^{1-\sigma}}{1-\sigma}.$$ \hspace{1cm} \sigma \text{ is set to } 2

$$\log(y_t) = \rho \log(y_{t-1}) + \varepsilon_t^y.$$ \hspace{1cm} \rho = 0.945 \text{ and } \eta = 0.025.

The dirty laundry: "This specification for default costs gives the model flexibility such that higher default probabilities can be calibrated. Mechanically the asymmetric costs increase the range of risky borrowing because the value of autarky is a less sensitive function of the shock."
Calibration

<table>
<thead>
<tr>
<th></th>
<th>Values</th>
<th>Target Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discount factor</td>
<td>$\beta = 0.953$</td>
<td>3% default probability</td>
</tr>
<tr>
<td>Probability of re-entry</td>
<td>$\theta = 0.282$</td>
<td>Trade balance volatility 1.75</td>
</tr>
<tr>
<td>Output costs</td>
<td>$\hat{y} = 0.969E(y)$</td>
<td>5.53% debt service to GDP</td>
</tr>
</tbody>
</table>

Business Cycle Statistics in the Benchmark Model

<table>
<thead>
<tr>
<th></th>
<th>Default Episodes</th>
<th>$std(x)$</th>
<th>$corr(x, y)$</th>
<th>$corr(x, r^c)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest rates spread</td>
<td>24.32</td>
<td>6.36</td>
<td>-0.29</td>
<td></td>
</tr>
<tr>
<td>Trade balance</td>
<td>-0.01</td>
<td>1.50</td>
<td>-0.25</td>
<td>0.43</td>
</tr>
<tr>
<td>Consumption</td>
<td>-9.47</td>
<td>6.38</td>
<td>0.97</td>
<td>-0.36</td>
</tr>
<tr>
<td>Output</td>
<td>-9.60</td>
<td>5.81</td>
<td>-0.29</td>
<td></td>
</tr>
</tbody>
</table>

Other Statistics

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Mean Spread</th>
<th>3.58</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Debt (% output)</td>
<td>5.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Default Probability</td>
<td>3.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
But Argentina defaulted on $100 million worth of external public debt, which was 37% of 2001 GDP, or 51% of GDP at end 2000 (almost 500% of exports!)

...bottom line, we are far from understanding sovereign debt!

<table>
<thead>
<tr>
<th>Business Cycle Statistics in the Model with Risk Averse Kernel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Default Episodes</td>
</tr>
<tr>
<td>Interest rates spread</td>
</tr>
<tr>
<td>Trade balance</td>
</tr>
<tr>
<td>Consumption</td>
</tr>
<tr>
<td>Output</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Debt (% output)</td>
</tr>
<tr>
<td>Default Probability</td>
</tr>
<tr>
<td>Mean Spread</td>
</tr>
</tbody>
</table>