Modeling General-Equilibrium Macroeconomic Stress Scenarios in MATLAB

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Macroprudential Policy…Is What?

- Narrow versus broader scope
- Broad policy objectives
  - Minimize incidence of balance sheet crises
  - Limit disruptions to key financial services
- Key elements in macroprudential analysis
  - Tail-risk distress scenarios
  - Feedback between balance sheets and real economy
  - Possibility of severe nonlinearities
- Models to support macroprudential policy
Plan of Presentation

- Policymaking Perspective
- Modeling Perspective
- Simulation Experiment
- Programming Perspective
POLICYMAKING PERSPECTIVE
Macroprudential Policy Exercise

Assess risks

Design macro(-economic/-financial) stress scenario(s)
- Slow-burn (low-frequency) shocks and risks
- Unlikely yet plausible scenarios with large impact

Evaluate impact of scenario(s)
- Resilience of sectoral balance sheets
- Feedback between financial and real

Communicate with policy makers
- Consider possible policy responses

Communicate to public
- Regular Financial Stability Reports
General Equilibrium Model Framework

- Empirical estimates (PD, LGD, EAD, etc)
- Structural models
- Sectoral analysis
- Time series analysis
- CCA
- Spreadsheet scenarios
- Financial stability analysis
- Real economy and monetary policy analysis

Spreadsheet scenarios:

| 3764 | 657 |
| 3638 | 1125 | 90354 | 4022 |
| 507 | 908 | 28384 | 78761 |
| 1209 | 8763 | 3321 | 20567 |
| 4545 | 284 | 374 | 3234 |
Role of General Equilibrium Models

- Integrate all pieces of information
- Balance sheet consistency across sectors and time
- Facilitate internal communication (explicit assumptions, most critical assumptions)
- Make process accountable
- Make external communication transparent, credible
- Model-based scenario analysis, not accurate probabilistic predictions
Limitations…

- Fundamental uncertainty
- Nonlinear feedback
- Corridor stability
- Estimation and backtesting difficult in crisis modeling
  - Distress episodes are few and far apart
  - Each has a different cause
  - Need to evaluate international evidence

Common variety of macro models not well-suited
Macro Model with Credit Risk

**Real economy**
- Relatively standard (DSGE) structure
- Monetary economy
- Optimizing agents with finite (short) planning horizons
- Mixed expectations

**Financial sector**
- Credit risk on loan books
- Asymptotic single factor risk model
- Advanced IRB to model regulatory capital constraints
Structure of Model

Real economy

- Producers
- Exporters

Households

Banking sector

- Loan portfolio
- Resident deposits
- Nonresid deposits
- Other assets
- Bank capital

Exports and imports

Rest of world
Banking sector

Real economy

Producers

Exporters

Households

Loan portfolio

Resident deposits

Nonresidential deposits

Other assets

Bank capital

Exports and imports
Demand for Deposits

\[ \Delta_t = \phi \left[ P_{C,t} C_t + P_{l,t} I_t + \kappa P_{H,t} H_t \right] \]

\[ \Delta_t = R_{t-1} D_{t-1} - R_{L,t-1} L_{t-1} + NL_t \]

Real economy

- Producers
- Exporters

Banking sector

Exports and imports
Individual Bank Loans

\[ R_{L,t}^i L_t^i > k \exp\left( u_{t+1}^i \right) P_{H,t+1} H_t^i \Rightarrow \text{default} \]

\[ R_{L,t}^i \left[ 1 - \lambda \Phi \left( \frac{\log \frac{R_{L,t}^i L_t^i}{k P_{H,t} H_t^i}}{\sigma} - E_t \left[ \frac{\log \frac{P_{H,t+1}}{P_{H,t}}}{\sigma} \right] \right) \right] = R_t^* \]
Bank Capital Regulation

\[ h_t^i(q) = \Phi \left( \frac{\Phi^{-1}(pd_t^i) - \Phi^{-1}(q) \sqrt{\rho}}{\sqrt{1 - \rho}} \right) \]

\[ \frac{E_t^i}{L_t^i} \geq 1 - \frac{R_{L,t}^i}{R_t} \left[ 1 - \lambda h_t^i(q) \right] \]
PROGRAMMING PERSPECTIVE
IRIS Toolbox

60+ classes, 30+ packages, 2,300+ functions

www.iris-toolbox.com

Structural modeling (DSGE)

MV time series analysis

Time series and database management

Reporting Documentation
Model Related Classes and Packages

- @economy
  - @agent
  - @stock
  - @flow
  - @stocklike
  - @flowlike
- @model
  - @modelobj
    - @preparser
    - @theparser
    - +irisopt
  - +logdist
    - @poster
    - @systempriors
- @hlastsyst
- @namedmat
- @userdataobj
- @getsetobj
- @fragileobj
Building Model Equations

- Two types of equations
  - Behavioral rules
  - Stock-flow and other identities
- Behavioral rules
  - Optimizing principles
  - Rules of thumb
  - Empirical equations
- Stock-flow identities
  - Logical structure of the model
## Transactions Flow Matrix

### Market clearing

<table>
<thead>
<tr>
<th>Transaction flows</th>
<th>Households</th>
<th>Producers</th>
<th>Exporters</th>
<th>Banks</th>
<th>Central Bank</th>
<th>Rest of world</th>
<th>Σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumption</td>
<td>−PC×C</td>
<td>PC×C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Wage bill</td>
<td>W×N</td>
<td>−W×NY</td>
<td>−W×NX</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Imports</td>
<td>−PM×MY</td>
<td>−PM×MX</td>
<td></td>
<td></td>
<td>PM×M</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Exports</td>
<td>PX×X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>−PX×X</td>
<td>0</td>
</tr>
<tr>
<td>Distrib surplus producers</td>
<td>Π</td>
<td></td>
<td>−Π</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Distrib surplus banks</td>
<td>Ω</td>
<td></td>
<td>−Γ</td>
<td></td>
<td>Γ</td>
<td>−Ω</td>
<td>0</td>
</tr>
<tr>
<td>Distrib surplus CB</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Deposit interest</td>
<td>RD(0)×D(0)</td>
<td></td>
<td>−RD(0)×D(0)</td>
<td></td>
<td>RL(0)×L(0)</td>
<td>−L(0)[1+RL(0)]×UL</td>
<td>0</td>
</tr>
<tr>
<td>Loan interest</td>
<td>−RL(0)×L(0)</td>
<td></td>
<td>RL(0)×L(0)</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Loan loss</td>
<td>L(0)[1+RL(0)]×UL</td>
<td></td>
<td>−L(0)[1+RL(0)]×UL</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>CB liquidity surplus interest</td>
<td></td>
<td>R(0)×B(0)</td>
<td>−R(0)×B(0)</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Net foreign liabs interest</td>
<td>−RF(0)×F(0)</td>
<td></td>
<td>RF(0)×F(0)</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Net acquisition of housing</td>
<td>−PH×ΔH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Chng in deposits</td>
<td>−ΔD</td>
<td></td>
<td>ΔD</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Chng in loans</td>
<td>ΔL</td>
<td></td>
<td>−ΔL</td>
<td></td>
<td>ΔB</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Chng in CB liquidity surplus</td>
<td>−ΔB</td>
<td></td>
<td>ΔB</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Chng in foreign liabs</td>
<td>ΔF</td>
<td></td>
<td>−ΔF</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Σ</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Budget constraints
## Net Worth Matrix

### Delegated agents

<table>
<thead>
<tr>
<th>Change in net worth</th>
<th>Households</th>
<th>Producers</th>
<th>Exporters</th>
<th>Banks</th>
<th>Central Bank</th>
<th>Rest of world</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opening net worth</td>
<td>VH0</td>
<td>0</td>
<td>0</td>
<td>VB(0)</td>
<td>VC(0)</td>
<td>VR(0)</td>
</tr>
<tr>
<td>Net acquisition of housing</td>
<td>PH×ΔH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chng in deposits</td>
<td>ΔD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chng in loans</td>
<td>−ΔL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chng in CB liquidity surplus</td>
<td>ΔB</td>
<td>ΔL</td>
<td>−ΔB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chng in foreign liabs</td>
<td>−ΔF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ΔF</td>
</tr>
<tr>
<td>Reval</td>
<td>ΔPH×H(0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revaluation of housing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revaluation of net foreign liabs</td>
<td>j×F(0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closing net worth</td>
<td>VH</td>
<td>0</td>
<td>0</td>
<td>VB</td>
<td>VC</td>
<td>VR</td>
</tr>
</tbody>
</table>

**Laws of motion for net worth (equity)**
Stock-Flow Builder

%Agents (Sectors)

households = Agent();
producers = Agent();
exporters = Agent();
centralBank = Agent();
banks = Agent();
restOfWorld = Agent();

%Ownership and Delegation

households.Ownership = [centralBank];
households.Delegates = [producers, exporters];
restOfWorld.Ownership = [banks];

%Flows

consumption = FlowLike.Goods();
labor = FlowLike.Goods();
imports = FlowLike.Goods();
exports = FlowLike.Goods();

%Link Agents and Flows

households.Debits = [consumption];
households.Credits = [labor];

producers.Debits = [labor, imports];
producers.Credits = [consumption];

exporters.Debits = [labor, imports];
exporters.Credits = [exports];

restOfWorld.Debits = [exports];
restOfWorld.Credits = [imports];
Stock-Flow Builder

%% Stocks

```
housing = StockLike.Physical( );
deposits = StockLike.SafeDeposit( );
loans = StockLike.RiskyLoan( );
netLiquidity = StockLike.SafeDeposit( );
netForeign = StockLike.SafeDeposit( );
```

%% Link Agents and Stocks

```
households.Assets = [ housing, deposits ];
households.Liabilities = [ loans ];
banks.Assets = [ loans, netLiquidity ];
banks.Liabilities = [ deposits, netForeign ];
restOfWorld.Assets = [ netForeign ];
```

%% Economy

```
x = Economy( );
x.addAgent( household, 'Hh' );
x.addAgent( producer, 'Pr' );
x.addAgent( exporter, 'Ex' );
x.addAgent( centralBank, 'Cb' );
x.addAgent( banks, 'Bk' );
x.addAgent( restOfWorld, 'Rw' );
x.addFlow( consumption, 'C' );
x.addFlow( labor, 'N' );
x.addFlow( exports, 'X' );
x.addFlow( imports, 'M' );
x.addStock( housing, 'H' );
x.addStock( deposits, 'D' );
x.addStock( loans, 'L' );
x.addStock( netLiquidity, 'B' );
x.addStock( netForeign, 'F' );
x.build( );
```
classdef Stock < handle

    properties
        HasPrice % true: Volume*Price, false: Value
        HasCashFlow % true: Next period CF prop to Value, false: No CF
        HasLoss % true: Loss on value and CF, false: No loss
        HasDeprec % true: Depreciation of volume, false: No depreciation
    end

    methods
        function This = Stock( HasPrice, HasCashFlow, HasLoss, HasDeprec )
            This.HasPrice = HasPrice;
            This.HasCashFlow = HasCashFlow;
            This.HasLoss = HasLoss;
            This.HasDeprec = HasDeprec;
        end

    classdef StockLike < Stock

        enumeration
            %
            SafeDeposit (% false, true, false, false)
            RiskyLoan (% false, true, true, false)
            Physical (% true, true, false, true)
            Share (% true, true, false, true)
        end

        methods

Behavioral Equations (Regexp Parser)

!substitutions

UU := (bet*((1-chiv)/(Ve - chiv*V )))^sgmc;
NO := (n*&NY);
RR := (1 / [ R/RL / (lmb*normpdf(log(Je)/varsgm)/varsgm) - 1 ]); 

!transition_equations

% Households
%-----------------

1 = ((C-chic*&C)/(1-chic))^sgmc * Lmb * PC *(1 + dc*Phi) ...
!! 1 = C^sgmc * Lmb * PC *(1 + dc*Phi);

R{-1}*D{-1} - (RL{-1}-1+the)*L{-1} + The - DA = dc*PC*C + dh*PH*KH;

Phi = RL/(R+Psi) + Psi - 1;
%$UU*$*(R+Psi)/dPCe = Lmb*PC;

Lmb*Phi = ...
$UU*$a*(ups-1) * (V/L) * (L/DA)^ups ...
* ((RL-1+the)*exp(EEPDU)/R)^(ups-1);

$UU*$RL*(1+$RR$)/dPCe =# Lmb*PC*(1+Phi-Psi);
SIMULATION EXPERIMENT
House Price Bubble and Burst

- Irrational expectations
- House price growth
- Easier cheaper credit
- Risk perceptions down
- Consumption, real economy
House Price Bubble and Burst

- Irrational expectations
  - Sequence of shocks
- Burst of the bubble
  - Unexpected event
  - House prices go down to “fundamentals”
  - Painful deleveraging in both real and financial sector
- Re-simulate with loan-to-value caps
  - Inequality constraint in households decision
  - Complementary slackness translated into $\min(...)$