A Computable General Equilibrium (CGE) Model of Banking System Stability: Case of Jamaica

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OUTLINE OF PRESENTATION

- Motivation
- Literature review
- Overview of CGE Framework
- Agents in the framework
- Implementation
- Calibration
- Simulation Results
- Conclusion

Motivation

- Structural macroeconomic models, complex frameworks that allow for interactions between agents, are becoming common
- Most mainstream macroeconomic frameworks are based on an implausible assumption that no economic agent ever defaults.
- Can financial stability be modelled explicitly in such frameworks?
- Can policy be informed by financial stability considerations?

Bank Fragility Literature

PARAMETRIC ESTIMATION TECHNIQUES

Gavin & Hausman (1996)

Sachs et. al. (1996)

INSOLVENCY MOTIVATED BANK DISTRESS

Akram et. al (2007)

Goodhart et al (2006)

NON- PARAMETRIC ESTIMATION TECHNIQUES

Kaminsky et. al (1998)

Honohan (1997)

LIQUIDITY MOTIVATED BANK DISTRESS

Allen & Gale (1998)

Morris and Shin (2000)

Empirical

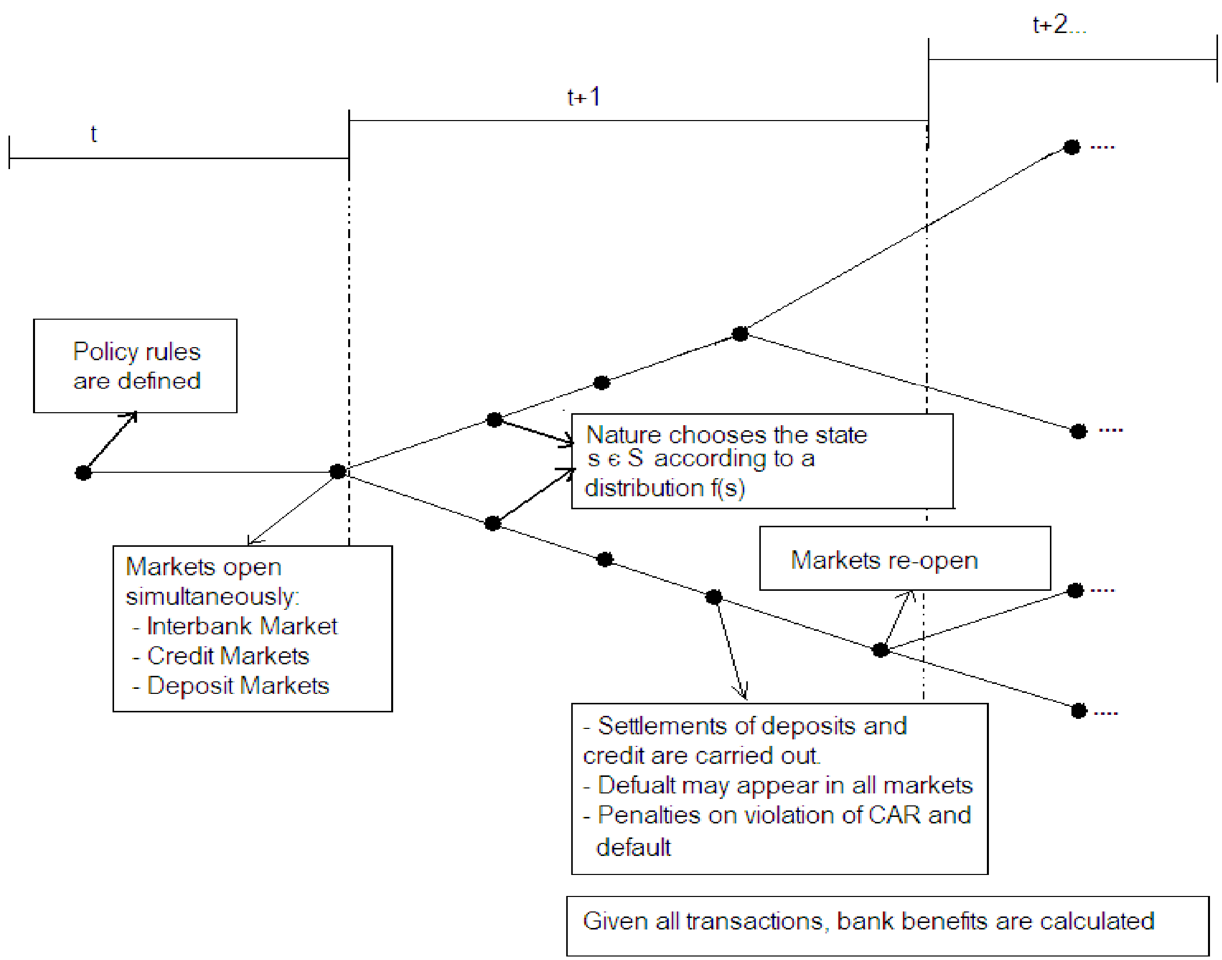
Theoretical

Overview of Framework

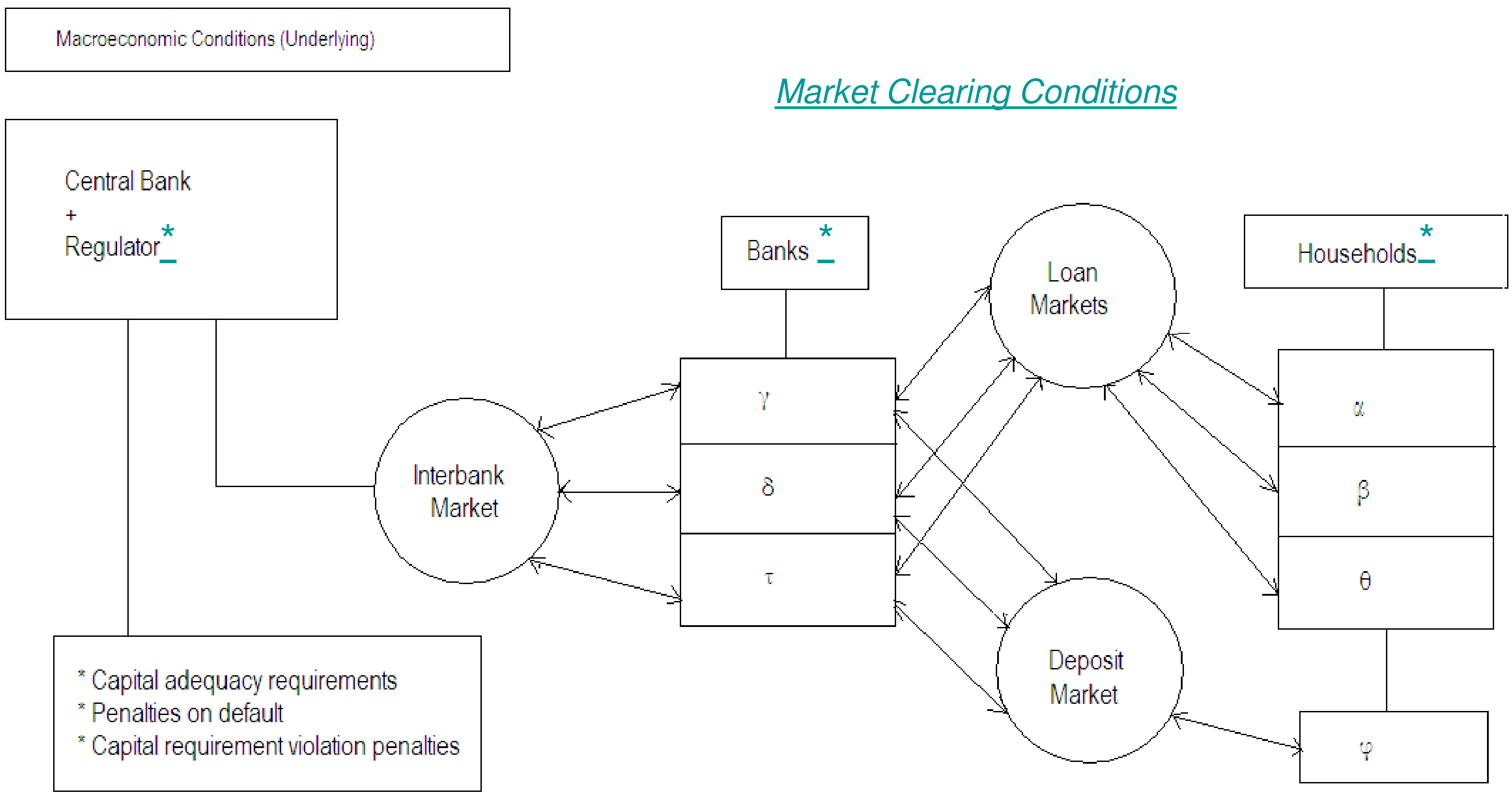
(Goodhart et. al 2006)

- **Agents**
  - Heterogeneous banks: B = $b \in B = \{\gamma, \delta, \tau\}$
  - Private Agents: H = $h \in H = \{\alpha^{\gamma}, \beta^{\delta}, \theta^{\tau}, \phi\}$
  - Central bank ~ Regulator
- **Markets**
  - Interbank market (B, CB)
  - Loan market (B, H)
  - Deposit market (B,H)
- **Time horizon:** $T = \{0,1 ...... \infty\}$
- **S** = {*i (good), ii (bad)*}. P(*s=i*)=*p*.

Time Structure of CGE Model



Overview of CGE Model



Regulator – Central Bank

Regulator – Central Bank

A set of parameters that affect the objective function and constraints of the banks.

- Regulator
  - Sets capital adequacy requirements: $\overline{k}^{b}_{t+1,s}$
  - Imposes penalties for failure to meet capital adequacy requirements: $\lambda^{b}_{k,s}$
  - Imposes penalties on default: λ^{b}_{s}
  - Sets the risk weight on market book investments, loans and interbank loans: $(\overline{\omega}, \omega, \tilde{\omega})$.
- Central Bank
  - Conducts open market operations (OMOs)
  - *Decides* on the interbank rate ρ

BACK

Banking Sector

- The asset side of their balance sheets consists of loans, interbank lending, and investments, while liabilities include deposits, interbank borrowings, other liabilities and capital.

- Banks take all interest rates as exogenously determined.

- Each sector is distinguished by its unique portfolio deriving from different capital endowments and risk return preferences.

- Banks borrow from the non-bank private sector by way of deposits and from each other and the central bank via the interbank market. They also extend credit to the private sector and hold a diversified portfolio of investments

List of Variables

Assets

$\overline{m}_t^b$: amount of credit that bank b offers in the period t

A_t^b : bank b's investments

d_t^b : bank b's interbank lendings

Liabilities

$\mu_{d,t}^b$: bank b's deposits

μ_t^b : bank b's debt in the interbank market in period t

e_t^b : bank b's capital

Default Metrics

$\upsilon_{t+1,s}^b$: repayment rate of bank b in t+1,s

$v_{t+1,s}^{h^b}$: repayment rate of h_t^b in t+1, s

$\tilde{R}_{t+1,s}$: repayment rate expected by banks from their interbank lending in t+1

$k_{t+1,s}^b$: Capital adequacy ratio

Interest Rates

r_t^b : lending rate offered by b

$r_{d,t}^b$: deposit rate offered by b

ρ_t : interbank rate in period t

Bank's Optimization Problem

Bank's optimization problem

QUADRATIC FUNCTION OF EXPECTED PROFITABILITY

Max

$$\max_{\overline{m}_t, \mu_t^b, d_t^b, \mu_{d,t}^b, \upsilon_{t+1,s}^b, s\in S} \quad E_t\left(\prod\nolimits_{t+1}^b\right) = \sum_{s\in S} p_s\left[\frac{\pi_{t+1,s}^b}{10^{10}} - c_s^b\left(\frac{\pi_{t+1,s}^b}{10^{10}}\right)^2\right]$$

$$-\sum_{s\in S} p_s\left[\lambda_{ks}^b \max[0, \bar{k}_{t+1,s}^b - k_{t+1,s}^b] + \frac{\lambda_s^b}{10^{10}}[\mu_t^b - \upsilon_{t+1,s}^b \mu_t^b] + \frac{\lambda_s^b}{10^{10}}[\mu_{d,t}^b - \upsilon_{t+1,s}^b \mu_{d,t}^b]\right]$$

Subject to balance sheet constraint

$$\overline{m}_t^b + A_t^b + d_t^b = \frac{\mu_t^b}{(1+\rho_t)} + \frac{\mu_{d,t}^b}{(1+r_{d,t}^b)} + e_t^b + Others_t^b \qquad (1)$$

and

$$(1+\rho_t)\upsilon_{t+1,s}^b \mu_t^b + \upsilon_{t+1,s}^b \mu_{d,t}^b + Others_t^b + e_t^b$$

$$\leq \upsilon_{t+1,s}^{h^b}(1+r_t^b)\overline{m}_t^b + (1+r_t^A)A_t^b + \tilde{R}_{t+1,s} d_t^b (1+\rho_t), \qquad s\in S \qquad (2)$$

Bank's (cont'd).

where:

$$\pi_{t+1,s} = v_{t+1,s}^{h^b}(1+r_{d,t}^b)\overline{m}_t^b + (1+r_t^A)A_t^b + \tilde{R}_{t+1,s}d_t^b(1+\rho_t) - ((1+\rho_t)\upsilon_{t+1,s}^b\mu_d^b$$

$$+ (1+r_{d,t}^b)\upsilon_{t+1,s}^b\mu_{d,s}^b + others_t^b + e_t^b), s \in S \qquad (3)$$

Capital (t+1): $e_{t+1,s} = e_t^b + \pi_{t+1,s}^b, \qquad s \in S \qquad (4)$

Capital adequacy ratio:

$$k_{t+1,s}^b = \frac{e_{t+1,s}^b}{\overline{\omega} v_{t+1,s}^{h^b}(1+r_t^b)\overline{m}_t^b + \tilde{\omega}(1+r_t^A)A_t^b + \omega\tilde{R}_{t+1,s}d_t^b(1+\rho_t)}, \qquad s \in S \qquad (5)$$

BACK

Private Agents

Reduced-Form Equations

- Demand for loans

$$\ln(\mu_t^{h^b}) = a_{h^b,2} trend + a_{h^b,3} \ln[p(GDP_{t+1,i}) + (1-p)GDP_{t+1,ii}] + a_{h^b,4} r_t^b \qquad (6)$$

- Supply of deposits

$$\ln(d_{b,t}^{\theta}) = z_{b,1} + z_{b,2} \ln[p(GDP_{t+1,i}) + (1-p)GDP_{t+1,ii}] + z_{b,3}[r_{d,t}^{b}(p\upsilon_{t+1,i}^{b} + (1-p)\upsilon_{t+1,ii}^{b})]$$
$$+ z_{b,4} \sum_{b' \neq b \in B} [r_{d,t}^{b'}(p\upsilon_{t+1,i}^{b} + (1-p)\upsilon_{t+1,ii}^{b'})] \qquad (7)$$

Reduced-Form Equations (cont'd)

- Loan repayment rates

$$\ln(v^{h^b}_{t+1,s}) = g_{h^b,s,1} + g_{h^b,s,2} \ln[(GDP_{t+1,s}) + g_{h^b,s,3} [\ln(\overline{m}^{\gamma}_t) + \ln(\overline{m}^{\delta}_t) + \ln(\overline{m}^{\tau}_t)] \qquad (8)$$

- GDP

$$\ln(GDP_{t+1,s}) = u_{s,1} + u_{s,2} trend + u_{s,2} [\ln(\overline{m}^{\gamma}_t) + \ln(\overline{m}^{\delta}_t) + \ln(\overline{m}^{\tau}_t)] \qquad (9)$$

BACK

Market Clearing Conditions

(Dubey et al. 2005)

- Bank *b's* credit market clears

$$1+r_t^b = \frac{\mu_t^{h^b}}{\overline{m}_t^b}, h^b \in H^b, \forall b \in B \qquad (10)$$

- Bank *b's* deposit market clears

$$1+r_{d,t}^b = \frac{\mu_{d,t}^b}{d_{b,t}^\phi}, \forall b \in B \qquad (11)$$

- Interbank market clears

$$1+\rho_t = \frac{\overline{B}_t + \sum_{b \in B} \mu_t^b}{M_t + \sum_{b \in B} d_t^b} \qquad (12)$$

Equilibrium Conditions

The monetary equilibrium with banks and default (MEBD) in time t is a set of endogenous variables such that:

- All banks maximize their expected future payoff
- All markets clear
- Banks form correctly their expectations about repayment rates they receive from their interbank lending.
- The reduced form equations for GDP, deposit supply, credit demands, and household repayment rates are satisfied.

Implications of M.E.B.D

- Agents (B,H) may choose in equilibrium a positive level of default.
- Financially fragile regimes are not incompatible with the existence of orderly markets
- Role for the Bank in mitigating or preventing the detrimental consequences of financial fragility.

Implementation

Bank's optimization problem

```
Sets
        b         banks / commercial, merchant, building /
        s         state / normal, extreme /
        t         time /2005*2007/
        h         household-borrower / Alpha, Beta, Theta /   ;
```

Max

```
eqfinprofit(b,s,t).. fprof(b,s,t)  =e= p(s)*(pr(b,s,t) - bcost(b,s,t));
eqbuscost(b,s,t)..    bcost(b,s,t)  =e=  c(b,s)*(sqr(pr(b,s,t)));
```

```
eqpenalty(b,s,t)..    cost(b,s,t) =e= p(s)*((lamda(b,s)*((sqrt(sqr(kbar(b,s) - kdymic(b,s,t)) + sqr(epsilon)) + (kbar(b,s) - kdymic(b,s,t)))/2))
+ lamdan(b,s)*(1 - rpb(b,s,t))*muint(b,t) + lamdan(b,s)*(1 - rpb(b,s,t))*mub(b,t));
```

Subject to balance sheet constraint

```
balcons(b,t).. mbar(b,t) + dint(b,t) + OA(b,t) - (muint(b,t)/(1 + rho(t))) - (mub(b,t)/(1 + rbd(b,t))) - cap(b,t)  -  ol(b,t) =e= 0;
```

and

```
posprofit1(b,'normal',t).. (1 + rho(t))*rpb(b,'normal',t)*muint(b,t) + (1 + rbd(b,t))*rpb(b,'normal',t)*mub(b,t) + ol(b,t) + cap(b,t)
 - rph(b,'normal',t)*(1 + rbd(b,t))*mbar(b,t) - (1 + roas(t))*OA(b,t) - rpint('normal',t)*dint(b,t)*(1 + rho(t)) =l= 0 ;
```

Calibration: The Data

- All data were quarterly 1996:Q1 - 1998:Q1
- All variables in logs and adjusted by CPI Index

Macro-economic Variables

1. Private Consumption
2. GDP
3. Unemployment rate
4. Inflation rate

Banking Sector Variables

1. Total Assets
2. Total Loans
3. Non-performing Loans
4. Unsecured Lending

Monetary Aggregates

1. M3

Interest Rates

1. Deposit rates (by bank and sector
2. Loan rates (by bank and sector
3. 180-day OMO rate

Calibration

The following reduced-forms were calibrated using econometric techniques:

- Household's demand for credit: Long-run elasticities were estimated using the error-correction representation of a cointegrated system between credit, money, private consumption, inflation, interest rates, and unemployment. (Chrystal and Mizen (2005)).

- Agent phi's supply of deposits: The parameters were obtained from the estimation of a fixed-effects model on a panel data set containing bank-specific information about deposits, interest rates and real GDP

Calibration (cont'd)

- Household's repayment rate: The parameters were obtained from the estimation of a random-effects model on a panel data set containing bank-specific information about deposits, interest rates and real GDP.

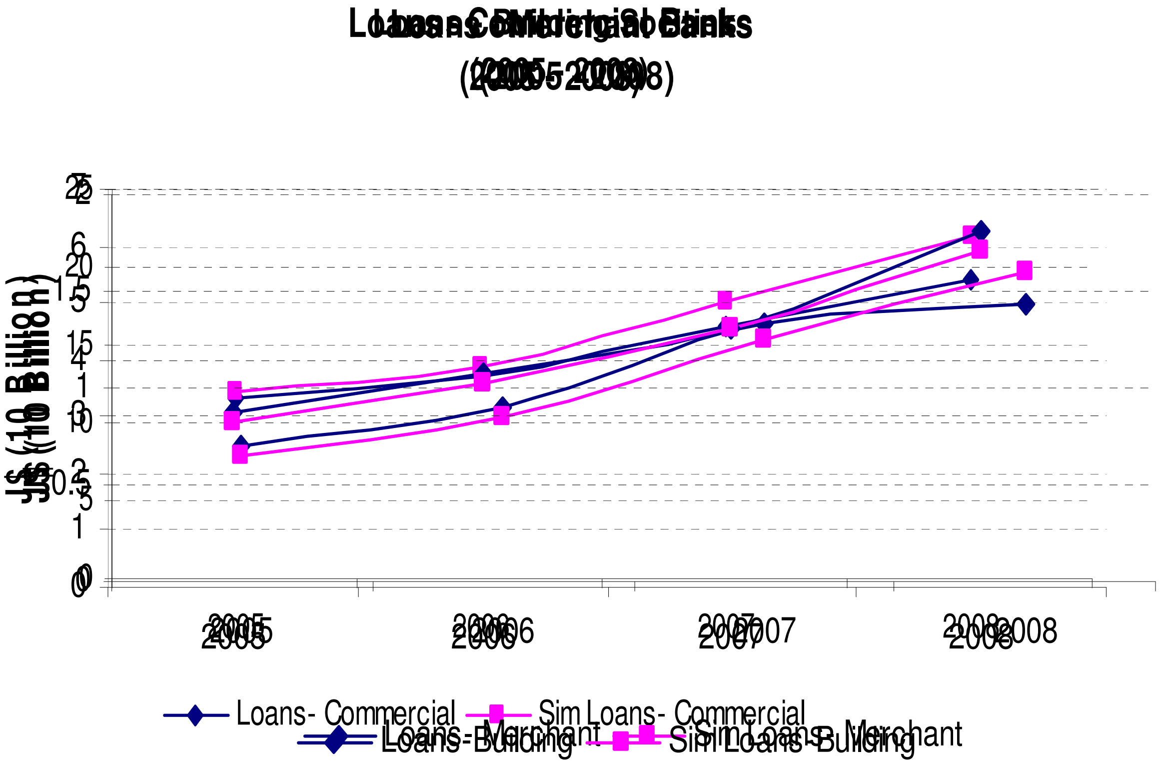
- Real GDP: The parameters were extracted from a cointegration vector for credit and real GDP, characterized by the presence of a drift.

Simulation Results

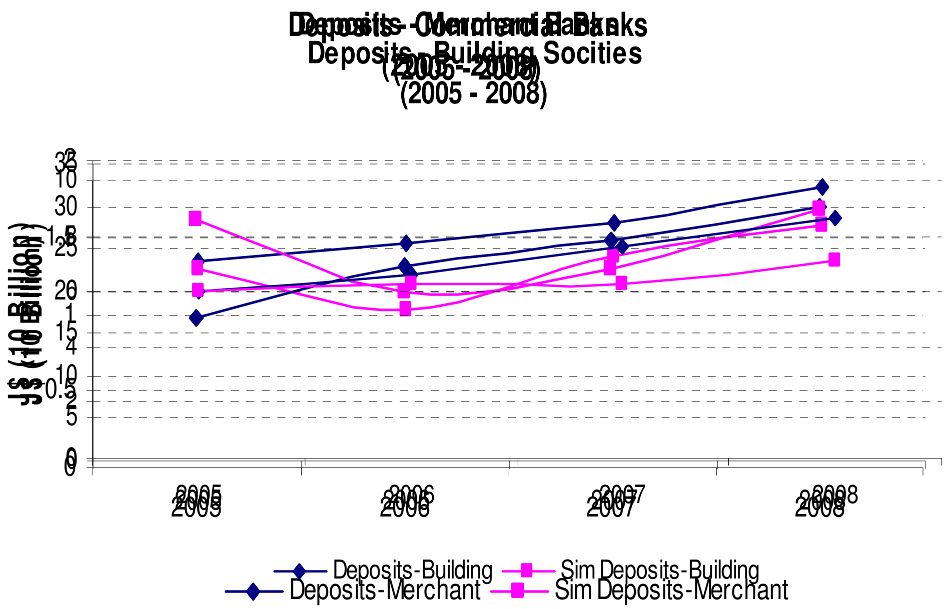
Initial Equilibrium (MEBD) *t=2005*

Initial Equilibrium			Exogenous variables in the model		
$r_t^{\gamma} = 0.1625$ $r_t^{\delta} = 0.1501$ $r_t^{\tau} = 0.1419$ $r_{d,t}^{\gamma} = 0.043$ $r_{d,t}^{\delta} = 0.081$ $r_{d,t}^{\tau} = 0.072$ $\mu_{d,t}^{\gamma} = 23.395$ $\mu_{d,t}^{\delta} = 1.625$ $\mu_{d,t}^{\tau} = 6.00$ $k_{t+1,i}^{\gamma} = 0.11$ $k_{t+1,ii}^{\gamma} = 0.08$	$k_{t+1,i}^{\delta} = 0.17$ $k_{t+1,ii}^{\delta} = 0.12$ $k_{t+1,ii}^{\tau} = 0.13$ $k_{t+1,ii}^{\tau} = 0.11$ $\pi_{t+1,i}^{\gamma} = 0.259$ $\pi_{t+1,ii}^{\gamma} = 0.254$ $\pi_{t+1,i}^{\delta} = 0.050$ $\pi_{t+1,ii}^{\delta} = -0.006$ $\pi_{t+1,i}^{\tau} = 0.048$ $\pi_{t+1,ii}^{\tau} = 0.032$ $e_{t+1,i}^{\gamma} = 0.011$	$e_{t+1,ii}^{\gamma} = 0.041$ $e_{t+1,i}^{\delta} = 0.014$ $e_{t+1,ii}^{\delta} = -0.04$ $e_{t+1,i}^{\tau} = 0.02$ $e_{t+1,ii}^{\tau} = 0.009$ $\tilde{R}_{t+1,i} = 0.989$ $\tilde{R}_{t+1,i} = 0.954$ $\mu_t^{\alpha^{\gamma}} = 13.9$ $\mu_t^{\beta^{\delta}} = 0.741$ $\mu_t^{\theta^{\tau}} = 3.303$ $\overline{B} = 1.87$	$Other\, r_t^{\gamma} = 3.403$ $Other\, r_t^{\delta} = 0.899$ $Other\, r_t^{\tau} = 0.249$ $g_{\alpha^{\gamma},i,1} = -5.035$ $g_{\alpha^{\gamma},ii,1} = -5.14$ $g_{\beta^{\delta},i,1} = -5.14$ $g_{\beta^{\delta},ii,1} = -5.531$ $g_{\theta^{\tau},i,1} = -5.593$ $g_{\theta^{\tau},ii,1} = -5.577$	$a_{\alpha^{\gamma},1} = -2.305$ $a_{\beta^{\delta},1} = -5.288$ $a_{\theta^{\tau},1} = -2.33$ $z_{\gamma,1} = -9.10$ $z_{\delta,1} = -14.34$ $z_{\tau,1} = -12.51$ $\overline{k}_{t+1,s(\forall s\in S)}^{\gamma} = 0.15$ $\overline{k}_{t+1,s(\forall s\in S)}^{\delta} = 0.20$ $\overline{k}_{t+1,s(\forall s\in S)}^{\tau} = 0.17$ $\lambda_{ks(\forall b\in B, s\in S)}^{b} = 0.1$	$\lambda_{i(\forall b\in B)}^{b} = 0.1$ $\lambda_{i(\forall b\in B)}^{b} = 1.1$ $z_{\gamma,2} = 7.358$ $z_{\delta,2} = 3.258$ $z_{\tau,2} = 3.258$ $z_{b,3(\forall b\in B)} = 0.656$ $z_{b,4(\forall b\in B)} = -0.923$ $r_t^{A} = 0.0997$ $p = 0.90$
$\overline{m}_t^{\gamma} = 12.025$ $\overline{m}_t^{\delta} = 0.644$ $\overline{m}_t^{\tau} = 2.893$ $d_{\gamma,t}^{\phi} = 22.431$ $d_{\delta,t}^{\phi} = 0.902$	$d_{\tau,t}^{\phi} = 5.594$ $d_t^{\gamma} = 6.465$ $d_t^{\delta} = 0.236$ $d_t^{\tau} = 1.241$ $\mu_t^{\gamma} = 3.148$	$\mu^{\delta} = 2.519$ $\mu_t^{\tau} = 0.403$ $\upsilon_{t+1,i}^{\alpha^{\gamma}} = 0.994$ $\upsilon_{t+1}^{\beta^{\delta}} = 0.975$ $\upsilon_{t+1}^{\theta^{\tau}} = 0.93$	$a_{h^b,3(\forall h\in H^b)} = 1.31$ $a_{h^b,4(\forall h\in H^b)} = -3.66$ $A_t^{\gamma} = 16.01$ $A_t^{\delta} = 4.69$ $A_t^{\tau} = 4.02$	$e_t^{\gamma} = 4.084$ $e_t^{\delta} = 0.582$ $e_t^{\delta} = 1.652$	$\overline{\omega} = 1$ $\omega(\tilde{\omega}) = 0.2$ $\rho_t = 0.061$ $a_{\alpha^{\gamma},2} = 0.025$ $a_{\beta^{\delta},2} = 0.12$ $a_{\theta^{\tau},2} = 0.12$
$\upsilon_{t+1,ii}^{\alpha^{\gamma}} = 0.570$ $\upsilon_{t+1,ii}^{\beta^{\delta}} = 0.591$ $\upsilon_{t+1,ii}^{\beta^{\delta}} = 0.571$	$\upsilon_{t+1,i}^{\gamma} = 0.989$ $\upsilon_{t+1,ii}^{\gamma} = 0.954$ $\upsilon_{t+1,i}^{\delta} = 0.996$	$\upsilon_{t+1,ii}^{\delta} = 0.959$ $\upsilon_{t+1,i}^{\tau} = 0.997$ $\upsilon_{t+1,ii}^{\tau} = 0.950$	$c_i^{\gamma} = 0.23$ $c_{ii}^{\gamma} = 0.35$ $c_i^{\delta} = 0.12$ $c_{ii}^{\delta} = 0.96$	$g_{h,s,2(\forall h\in H^b)} = 1.203$ $g_{h,i,3(\forall h\in H^b)} = -0.02897$ $g_{h,ii,3(\forall h\in H^b)} = -0.0337$	

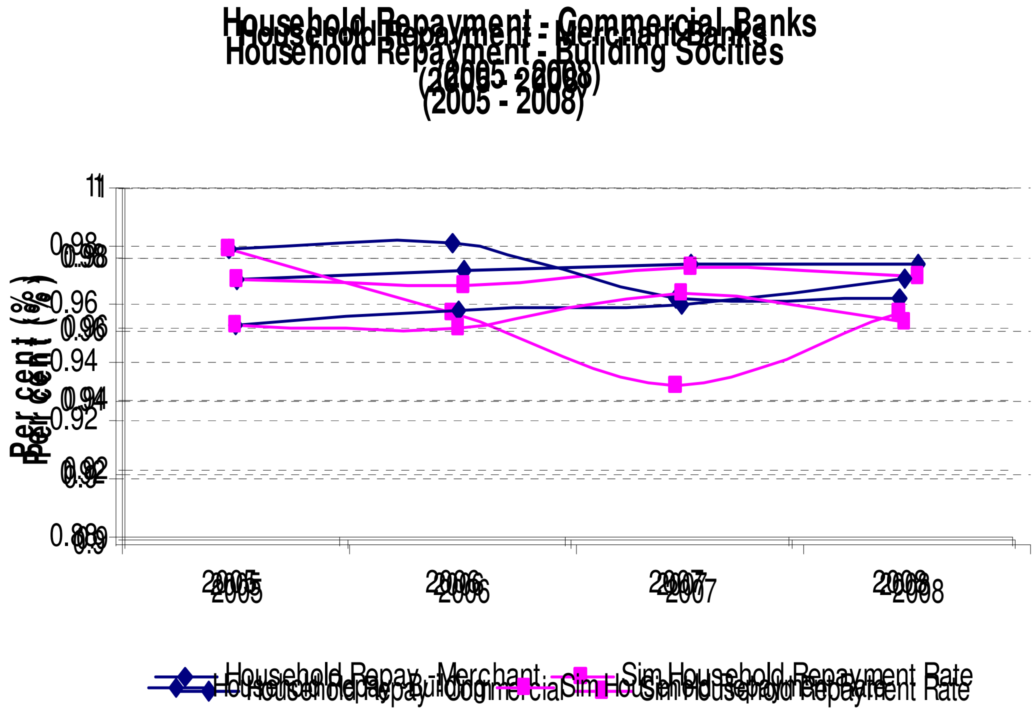
Simulated Loan Portfolio



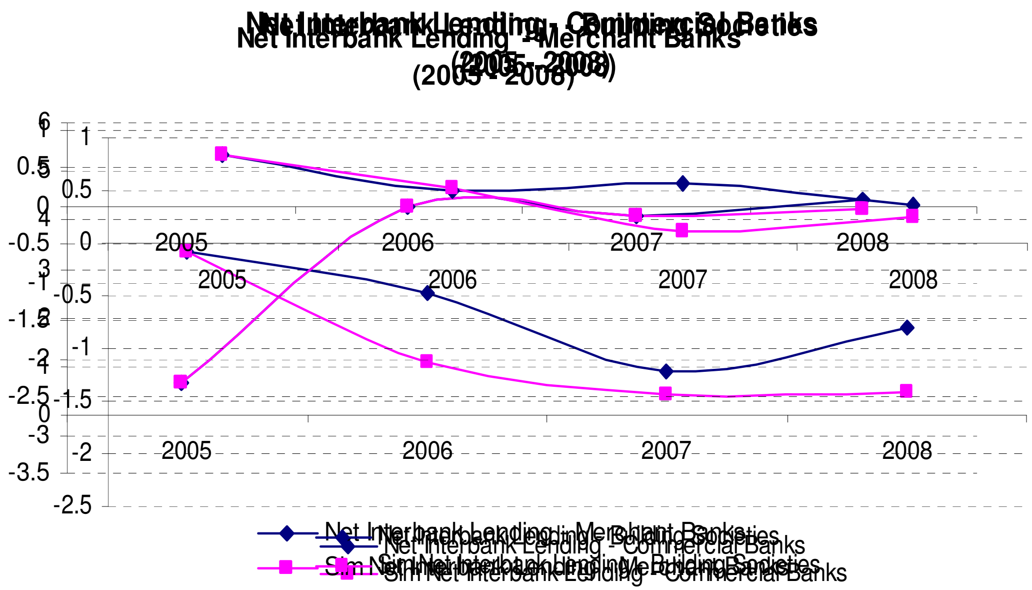
Simulated Deposits



Simulated Household Repayments



Simulated Net Interbank Lending



Conclusion

- Model performs satisfactorily in the prediction of medium-term trends which are relevant to the assessment of financial stability.
- Financial stability can be investigated in a single coherent framework which is empirically tractable as it is theoretically sound.

Research Agenda

- Calibration
- Evaluation of the consistency of macro-forecasts

Thank you!

Household's Demand for Loans

Johansen Cointegration tests

No. of CV	Trace Statistic	Critical Value (5%)	Prob.**
None *	256.41	159.53	0.00
At most 1 *	157.51	125.62	0.00
At most 2 *	100.92	95.75	0.02
At most 3	66.38	69.82	0.09
At most 4	37.82	47.86	0.31
At most 5	22.75	29.80	0.26
At most 6	9.45	15.49	0.33
At most 7	1.46	3.84	0.23

No. of CV	Max-Eigen Value	Critical Value (5%)	Prob.**
None *	98.90	52.36	0.00
At most 1 *	56.59	46.23	0.00
At most 2	34.54	40.08	0.18
At most 3	28.56	33.88	0.19
At most 4	15.07	27.58	0.74
At most 5	13.30	21.13	0.43
At most 6	7.99	14.26	0.38
At most 7	1.46	3.84	0.23

Household's Demand for Loans

Co-integrating Equation	CoinEq1
LM3(-1)	0.0
LPRIVCONS(-1)	0.0
LRGDP(-1)	-1.055690 (0.07711) [-13.6915]
LUNSEC(-1)	1.00
NCS(-1)	3.6692 (0.52615) [6.97378]
DS(-1)	0.0
UNEMPL(-1)	11.27959 (1.07783) [10.4651]
INFL(-1)	-0.486423 (0.74457) [-0.65330]

$$L_t = 1.05 \ln(GDP_{t+1}) - 3.66(CS_t) + 0.48(\pi_t) - 11.27(\Delta Unemp)$$

income elasticity parameter: 1.05

Credit spread parameter: -3.66

BACK

Household's phi supply of deposits

$$\ln(D_{i,t}) = \alpha_i + \beta_1 \ln(y_{t+1}) + \beta_2 (dr_{i,t}) + \beta_3 (dr^{'}_{i,t}) + \mu_{i,t}$$

Method: Pooled Least Squares			
Number of Observations	637		
Number of Individual Banks	14		
Dependent variable:	$\ln(D_{i,t})$		
	Coefficient	Std. error	t-Statistic
α_i	-36.38	10.56	-3.344***
β_1	3.458	0.896	3.746***
β_2	-0.356	0.034	-10.455***
β_3	-1.067	3.125	-0.398
Adj- R^2	0.82		

*** indicates significance at the 1.0 per cent level and * indicates significance at the 10.0 per cent level

BACK

Household Repayment Rates

$$\ln(1-NPL_{i,t+1}) = \alpha_i + \beta_1 \ln(GDP_{t+1}) + \beta_2 (loans_{i,t}) + \mu_{i,t}$$

Random-effects estimation of Household Repayment Rates

Method: EGLS			
Number of Observations	643		
Number of Individual Banks	14		
Dependent variable:	$\ln(1-NPL_{i,t+1})$		
	Coefficient	Std. error	t-Statistic
α_i	-15.24	2.01	-7.56***
β_1	1.303	0.173	7.506***
β_2	-0.0189	0.0092	-1.83*
Adj-R^2	0.1220		

*** indicates significance at the 1.0 per cent level and * indicates significance at the 10.0 per cent level

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