Aggregate Bank Capital and Credit Dynamics

N. Klimenko (Zürich) S. Pfeil (Bonn) J.-C. Rochet (Zürich, SFI and TSE) G. De Nicolò (IMF and CESifo)

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The views expressed in this paper are those of the authors and do not necessarily represent those of the IMF.

Motivation

- Financial regulators and central banks now control powerful macro-prudential tools for promoting systemic stability.
- Long-term impact on growth and financial stability?
- **Standard** DSGE models cannot really help: they were designed to reproduce short-term reactions of prices and output to monetary policy decisions.
- Monetary Policy and Macroprudential Policy have different objectives, different horizons and different instruments.
- To study the **long-term impact** of macro-prudential policies on output and financial stability, one needs a different type of model.
- We provide an example of such a model.

Our contribution

- General equilibrium dynamic model with financial frictions, in the spirit of *Brunnermeier-Sannikov (2014)* and *He-Krishnamurthy (2013)*.
- Banks are explicitly modeled.
- Bank capital serves as a **loss-absorbing buffer** and determines the volume of lending.
- Model allows the analysis of the **long-run** effects of minimum capital requirements on lending and systemic stability **(ergodic distribution)**.
- Main implications are in line with empirical evidence.

Related literature

1. **Macro-finance in continuous time**

   Brunnermeier-Sannikov (2014, 2015), He-Krishnamurthy (2012, 2013), Di Tella (2015), Phelan (2015).

2. **Welfare impact of capital requirements**
   - *Van den Heuvel (2008)*
   - *Martinez-Miera and Suarez (2014)*
   - *DeNicolò-Gamba-Lucchetta (2014)*
   - *Nguyen (2014)*
   - *Begenau (2015)*

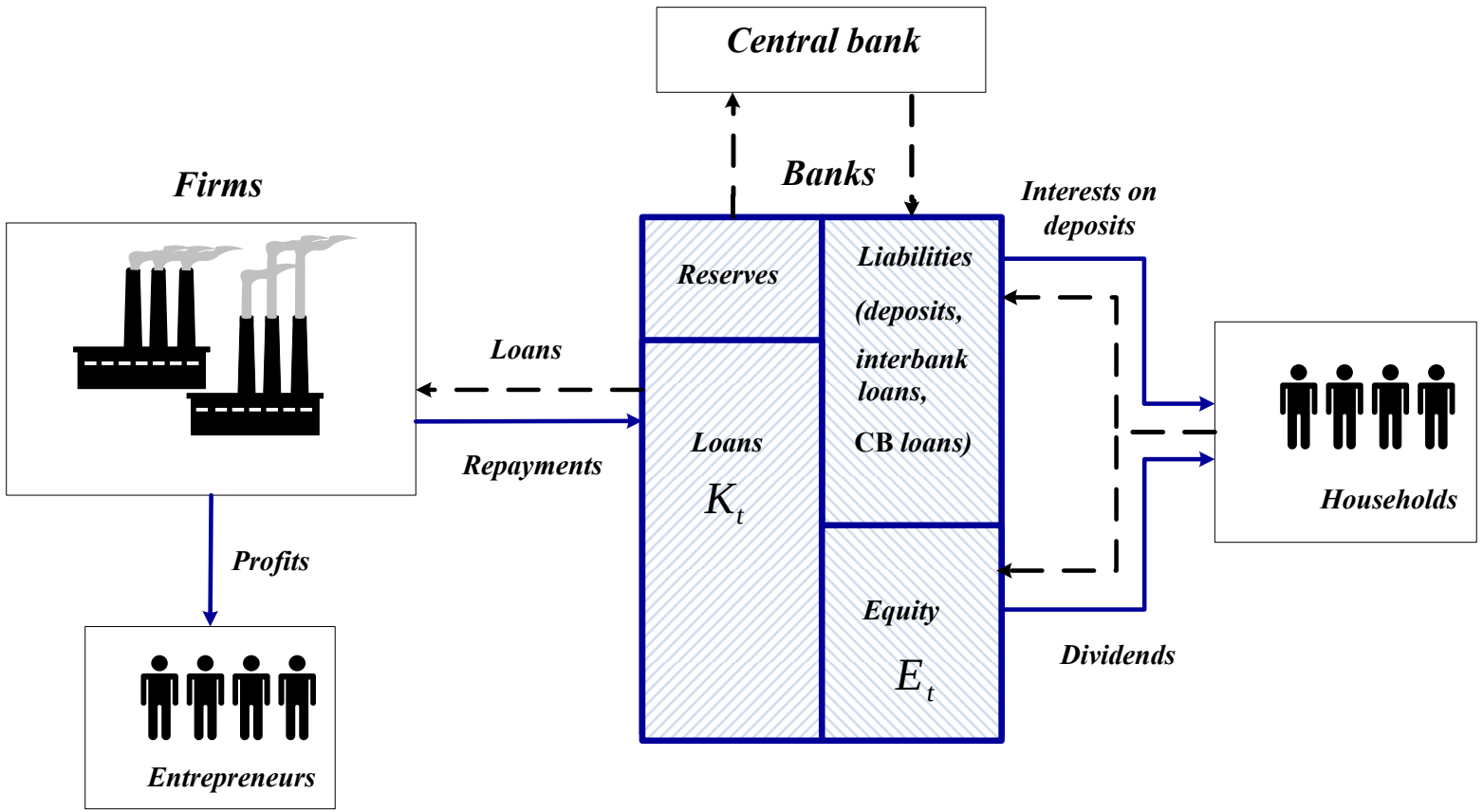
ROADMAP

1. Model
2. Competitive equilibrium
3. Long run dynamics
4. Application to macro prudential policy analysis

Model

- General equilibrium model: real sector and banking sector.
- One physical good, can be consumed or invested.
- Households invest their savings in bank deposits and bank equity.
- Banks invest in (risky) loans to entrepreneurs and reserves (can be <0).
- Entrepreneurs have no capital and must borrow from banks, who monitor them: no direct finance.
- Central bank provides reserve and refinancing facilities to equilibrate the interbank lending market.

GLOBAL PICTURE



Remark: equity acts as a buffer to guarantee safety of deposits (no deposit insurance) and interbank borrowings.

MODEL

- Households and entrepreneurs are risk neutral and discount future consumption at rate ρ.
- Interbank rate r is fixed and less than ρ.
- Households receive interest r_D on deposits. At equilibrium $r_D = r$.
- Households derive utility from holding riskless deposits (*transactional demand for safe assets* as in Stein (2012)).
- Supply of deposits is fixed and is a decreasing function of $(\rho - r)$.
- For simplicity, $r \equiv 0$ in this presentation.
- Easy to extend for $r > 0$.

MODEL: FIRMS

Firms:

- can borrow 1 unit of productive capital from banks at time t, must repay $1 + R_t dt$ at $t + dt$
- if borrow, produce xdt unit of good, where x is distributed over $[0, \overline{R}]$ with density $f(x)$
- borrow when $x > R_t$; **aggregate demand for loans** is a decreasing function of loan rate R

$$L(R) = \int_R^{\overline{R}} f(x)dx$$

- productive capital is destroyed (default) with probability

$$pdt + \sigma_0 dZ_t,$$

where $\{Z_t, t \geq 0\}$ is a standard Brownian motion **(aggregate shocks)**

MODEL: BANKS

- **Aggregate shocks** in the real sector translate into banks'profits/losses
- Book equity of an individual bank evolves:

$$de_t = \underbrace{k_t[(R_t - p)dt - \sigma_0 dZ_t]}_{\text{return on a bank's loans}} - \underbrace{d\delta_t}_{\text{dividends}} + \underbrace{di_t}_{\text{recapitalizations}},$$

  where k_t is the volume of lending to firms at time t

- **Aggregate** bank equity evolves:

$$dE_t = \underbrace{K_t[(R_t - p)dt - \sigma_0 dZ_t]}_{\text{return on total loans}} - \underbrace{d\Delta_t}_{\text{dividends}} + \underbrace{dI_t}_{\text{recapitalizations}},$$

  where K_t is aggregate lending

- **Main friction:** issuing new equity entails proportional cost γ

ONE-PERIOD EXAMPLE

- 2 dates: $t = 0$ and $t = 1$, length of time period $h = 1$.
- Firms' default probability:

$$\begin{cases} p - \sigma_0, & \text{with probability } 1/2 \textit{ (positive shock)} \\ p + \sigma_0, & \text{with probability } 1/2 \textit{ (negative shock)} \end{cases}$$

- At $\boldsymbol{t = 0}$ a typical bank starts with equity e,
  - may distribute dividends $\boldsymbol{\delta \geq 0}$ or issue new equity $\boldsymbol{i \geq 0}$,
  - borrows $\boldsymbol{d} > 0$ from depositors,
  - lends $\boldsymbol{k}$.
- ***Main friction:*** issuing new equity entails proportional cost γ.

AN INDIVIDUAL BANK'S PROBLEM

- At $\boldsymbol{t = 1}$ profits/losses are realized, bank equity becomes:

$$e^+ \equiv (e - \delta + i) + k\big[R - (p - \sigma_0)\big]$$
$$e^- \equiv (e - \delta + i) + k\big[R - (p + \sigma_0)\big],$$

- Bank capital must be sufficiently high to cover the worst possible loss:

$$e^- \geq 0$$

- Shareholders' problem:

$$v = \max_{\delta,i,k} \quad \left\{\delta - (1+\gamma)i + \frac{\left(\frac{1}{2}\right)e^+ + \left(\frac{1}{2} + \theta\right)e^-}{1+\rho}\right\},$$

θ denotes the Lagrange multiplier associated with constraint $\boldsymbol{e^- \geq 0}$.

AN INDIVIDUAL BANK'S PROBLEM

Shareholders' problem is separable:

$$v = eu + \max_{\delta \geq 0} \delta\big[1-u\big] + \max_{i \geq 0} \quad i\big[u-(1+\gamma)\big] + \max_{k \geq 0} \quad k\Big[\frac{(R-p)(1+\theta)-\theta\sigma_0}{1+\rho}\Big],$$

where

$$u \equiv \frac{1+\theta}{1+\rho}$$

is the *Market-to-Book ratio*.

- **FOCs:**

$$1-u \leq 0 \qquad (= \text{ if } \delta > 0)$$

$$u-(1+\gamma) \leq 0 \qquad (= \text{ if } i > 0)$$

$$-\frac{R-p}{R-(p+\sigma_0)} \geq \theta \qquad (= \text{ if } k > 0)$$

AN INDIVIDUAL BANK'S PROBLEM

- $u \geq 1 \quad \Rightarrow \theta > 0 \Rightarrow$ non-default constraint binds on individual and **aggregate** level
- Dividends are distributed ($\delta > 0$) when $E \geq E_{max}$, where

$$\boxed{u(E_{max}) = 1}$$

- New equity is raised ($i > 0$) when $E \leq E_{min}$, where

$$\boxed{u(E_{min}) = 1 + \gamma}$$

ONE-PERIOD EXAMPLE: COMPETITIVE EQUILIBRIUM

a) The loan rate $R \equiv R(E)$ is a decreasing function of aggregate capital and it is implicitly given by

$$E + L(R(E))\left[R(E) - (p + \sigma_0)\right] = 0$$

b) All banks have the same market-to-book ratio of equity that belongs to $[1, 1+\gamma]$ and is a decreasing function of aggregate capital.

$$u(E) = \left(\frac{1}{1+\rho}\right)\left(\frac{-\sigma_0}{R(E) - (p+\sigma_0)}\right)$$

c) Banks pay dividends when $E \geq E_{max} \equiv u^{-1}(1)$ and recapitalize when $E \leq E_{min} \equiv u^{-1}(1+\gamma)$.

ONE-PERIOD EXAMPLE: TAKE AWAY

1. Only the level of aggregate bank capital E matters for banks' policies

2. Banks' recapitalization and dividend policies are of the "barrier type" and are driven by the market-to-book value

3. Loan rate is decreasing in aggregate bank capital E

AN INDIVIDUAL BANK'S PROBLEM

- **Markovian competitive equilibrium:** $R_t = R(E_t)$ and $K(E_t) = L(R(E_t))$
- An individual bank chooses lending, dividend and recapitalization policies to maximize shareholder value:

$$v(e_t, E_t) = \max_{k_s, d\delta_s, di_s} \mathbb{E}\Big[\int_t^{+\infty} e^{-\rho(s-t)}(d\delta_s - (1+\gamma)di_s)\Big]$$

- Shareholder value is linear in e:

$$v(e, E) \equiv eu(E),$$

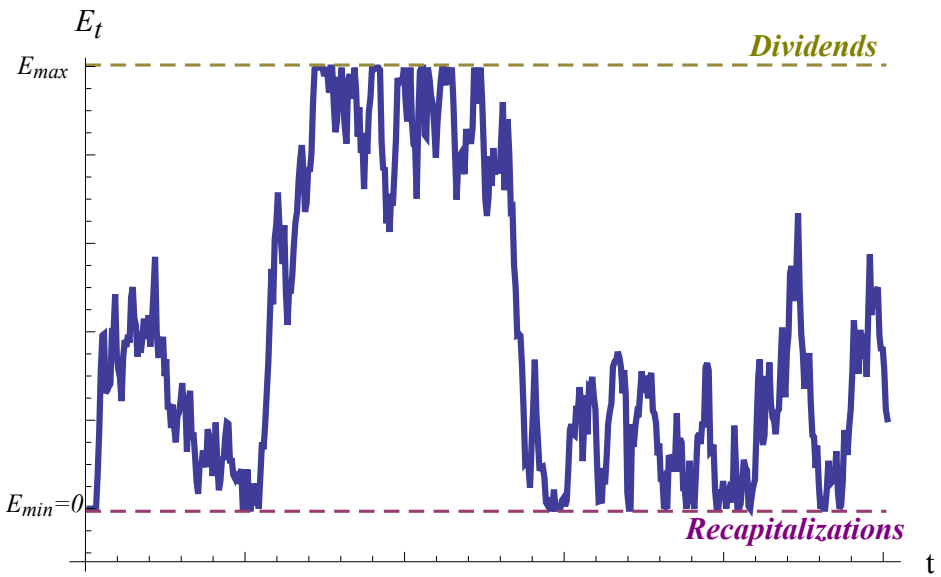
where $u(E)$ is the *Market-to-Book ratio*.

- Only aggregate capital E matters for banks' policies.

DIVIDEND AND RECAPITALIZATION POLICIES

Dividend/recapitalization policies of a "barrier" type:

- banks distribute dividends when $E_t = E_{max}$, such that $u(E_{max}) = 1$
- banks recapitalize when $E_t = E_{min} = 0$



Remark: E_{max} and E_{min} are determined by equilibrium forces on the market for bank equity.

EQUILIBRIUM LOAN RATE

- Positive loan spread, decreasing with E:

$$R(E) - p = \underbrace{\sigma_0^2 K(E)\Big[-\frac{u'(E)}{u(E)}\Big]}_{\text{“lending premium”}}, \qquad \text{where} \quad u'(E) < 0$$

- **Source of lending premium:** *implied risk-aversion* of bankers with respect to variations in aggregate capital

COMPETITIVE EQUILIBRIUM (CE)

- Aggregate bank capital evolves according to:

$$dE_t = L(R(E_t))\Big[(R(E_t) - p)dt - \sigma_0 dZ_t\Big],$$

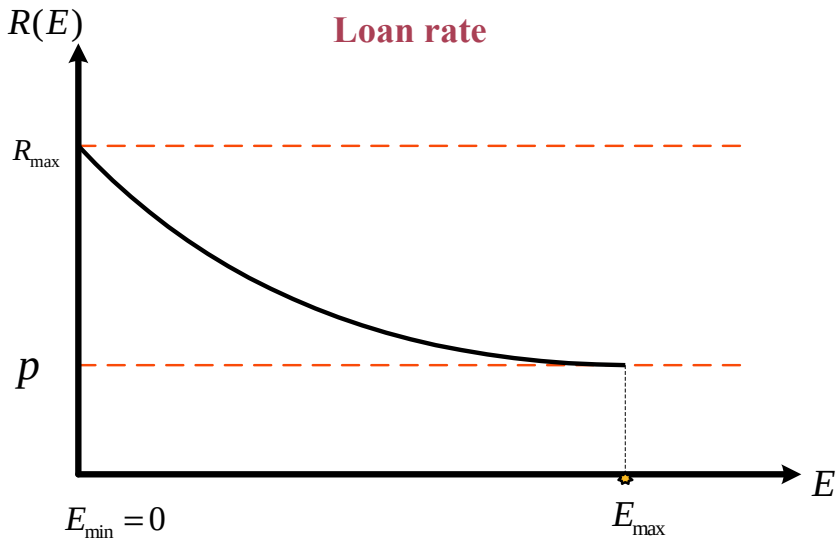
with reflection at $E_{min} = 0$ (recapitalizations) and E_{max} (dividends)

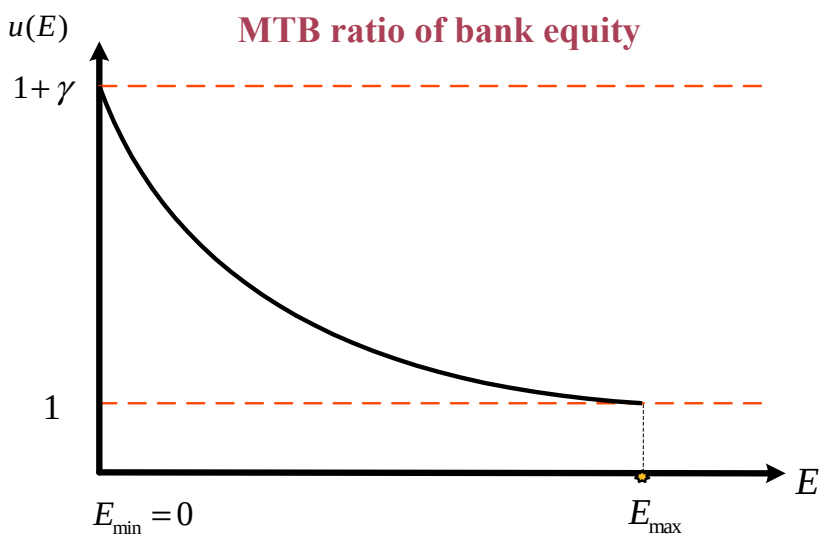
- The loan rate function $R(E) : [0, E_{max}] \to [p, R_{max}]$ solves

$$R'(E) = -\frac{2\rho\sigma_0^2 + (R-p)^2}{\sigma_0^2[L(R) - (R-p)L'(R)]}, \qquad R(E_{max}) = p$$

- R_{max} and E_{max} **increase with financing friction** γ

TESTABLE PREDICTIONS





Testable predictions: equilibrium loan rate and market-to-book ratio are decreasing functions of aggregate capital

EMPIRICAL EVIDENCE: DATA DESCRIPTION

- Panel of publicly traded banks in 43 advanced and emerging market economies (1992-2012):
  - **U.S. banks** (728 banks)
  - **Japan** (128 banks)
  - **Banks in advanced economies** (248 banks)
  - **Banks in emerging market economies** (183 banks)

Identifier	*Variable*	*Measurement*
ret	bank gross return on assets	total interest income/earning assets
mtb	market-to-book equity ratio	market equity/book equity
logta	bank size	Log(assets)
loanasset	% of loans to assets	total loans/total assets
bequity	bank book equity	bank book equity
npl	non-performing loans	non-performing loans in % of total assets
TBE	total bank equity	sum of bequity

EMPIRICAL EVIDENCE: SAMPLE STATISTICS

	US			Japan			Advanced (ex. US and Japan)			Emerging		
Variable	*Obs.*	*Mean*	*Std.Dev.*	*Obs.*	*Mean*	*Std.Dev.*	*Obs.*	*Mean*	*Std.Dev.*	*Obs.*	*Mean*	*Std.Dev.*
ret	10213	6.49	1.57	2116	3.18	1.66	4779	7.34	4.09	3015	9.99	5.01
mtb	9542	1.42	0.71	2151	1.19	0.64	4788	1.4	0.85	2914	1.61	0.99
logta	10991	13.54	1.65	2342	17.12	1.22	5148	16.26	2.39	3473	15.65	1.94
loanasset	10812	65.96	13.42	2091	68.25	9.98	4572	70.38	16.53	3074	66.43	15.74
bequity (US$ billion)	10923	0.98	9.19	2318	2.83	7.61	5133	5.23	14.16	3419	2.87	11.49
npl	10299	1.59	2.68	1770	4.11	2.89	2710	3.37	5.36	1937	5.92	8.78
TBE (US$ billion)	16742	486.69	352.6	3061	297.38	108.18	7185	59.77	76.73	5696	35.65	108.21

EMPIRICAL MODEL

$$Y_t = \alpha + \boldsymbol{\beta} E_{t-1} + \gamma X_{t-1} + \eta Dummy_t + \epsilon_t$$

- Focus on coefficient β (must be negative)
- Dependent variables: $Y = (ret, mtb)$
- Bank specific effects: $X = (bequity, logta, loanasset, npl)$
- Time-varying country specific effects: $Dummy$

EMPIRICAL EVIDENCE: CONDITIONAL CORRELATIONS

	US		Japan		Advanced (ex US and Japan)		Emerging	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
EXPLANATORY VARIABLES	**ret**	**mtb**	**ret**	**mtb**	**ret**	**mtb**	**ret**	**mtb**
TBE	-0.00416***	-0.000139***	-0.0124***	-0.00466***	-0.0123***	-0.00374***	-0.00280***	-0.00215***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
bequity	0.00232**	-0.00945***	0.0254***	-0.00316*	0.0117***	-0.00113*	0.0167***	-0.00160*
	[0.01]	[0.00]	[0.00]	[0.07]	[0.00]	[0.08]	[0.00]	[0.10]
logta	-0.0454***	0.157***	0.0220	0.204***	-0.366***	-0.0164**	-0.370***	-0.00726
	[0.00]	[0.00]	[0.45]	[0.00]	[0.00]	[0.01]	[0.00]	[0.41]
loanasset	0.0228***	-0.000590	0.00561***	0.00388	-0.0282***	-0.00195***	-0.0357***	-0.000738
	[0.00]	[0.23]	[0.00]	[0.29]	[0.00]	[0.00]	[0.00]	[0.43]
npl	0.0274***	-0.0414***	0.0386***	0.0369***	0.0181*	-0.0110***	-0.0103	-0.00892***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.09]	[0.00]	[0.16]	[0.00]
Constant	8.117***	-0.527***	6.897***	-1.002	16.88***	2.633***	24.22***	1.551***
	[0.00]	[0.00]	[0.00]	[0.11]	[0.00]	[0.00]	[0.00]	[0.00]
number of banks	728	728	128	128	248	248	183	183
Bank/years	9,736	8,899	1,534	1,598	2,600	2,600	1,772	1,772
R-squared	0.794	0.429	0.803	0.385	0.700	0.506	0.737	0.392
Robust pval in brackets								
*** p<0.01, ** p<0.05, * p<0.1								
Change in the dependent variable for a 1-standard deviation increase in TBE	**-1,47**	**-0,07**	**-1,34**	**-0,50**	**-0,94**	**-0,29**	**-0,30**	**-0,23**

Loan rate dynamics

- Loan rate $R_t = R(E_t)$ has **explicit** dynamics

$$dR_t = \boldsymbol{\mu}(\boldsymbol{R_t})dt + \boldsymbol{\sigma}(\boldsymbol{R_t})dZ_t, \qquad p \leq R_t \leq R_{max},$$

with

$$\boldsymbol{\sigma}(\boldsymbol{R}) = \frac{2\rho\sigma_0^2 + (R-p)^2}{\sigma_0\left(1 - (R-p)\frac{L'(R)}{L(R)}\right)} \quad \text{and} \quad \boldsymbol{\mu}(\boldsymbol{R}) = \sigma(R)h(R),$$

where $h(.)$ is explicit.

LONG RUN BEHAVIOR OF THE ECONOMY

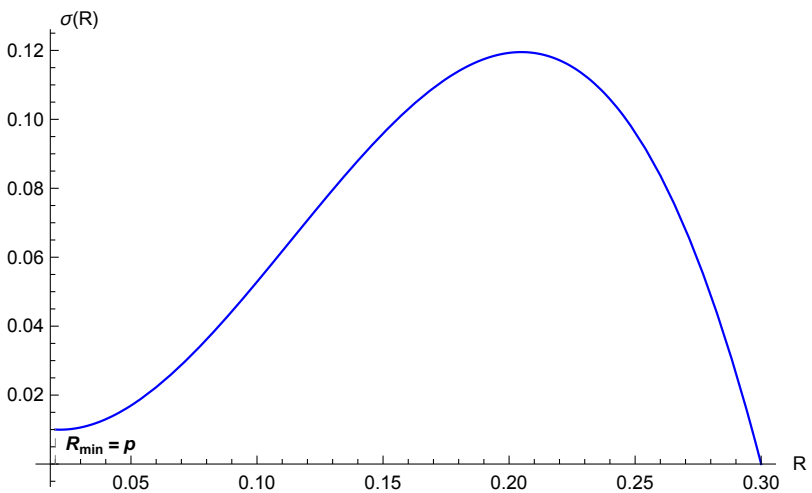
- Full description of the **long run behavior of the economy**: stochastic steady state
- It is characterized by the **ergodic density** function of R or E (shows how frequently each state is visited in the long run)
- We can numerically solve for the ergodic density function of R (no need for simulations):

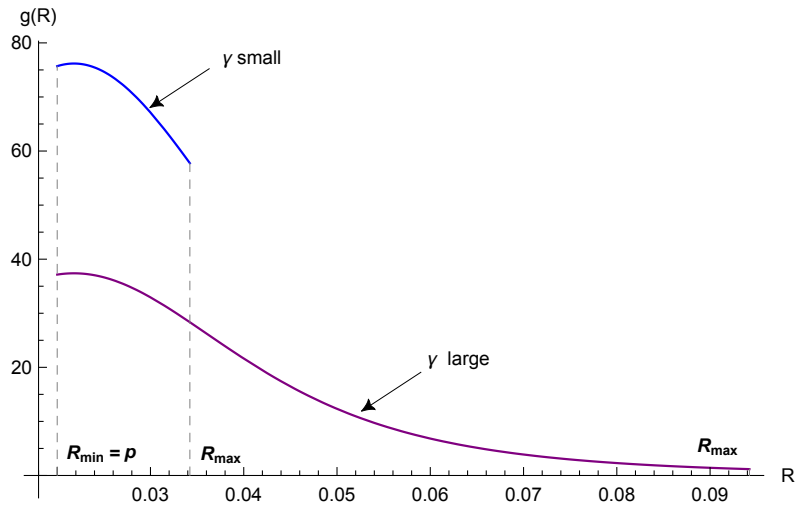
$$\boxed{\frac{g'(R)}{g(R)} = \frac{2\mu(R)}{\sigma^2(R)} - \frac{2\sigma'(R)}{\sigma(R)}, \quad \text{on} \quad [p, R_{max}]}$$

LONG RUN BEHAVIOR OF THE ECONOMY

- Particular specification: linear demand for loans

$$L(R) = \left(\frac{\overline{R} - R}{\overline{R} - p}\right) \qquad \text{where} \qquad \overline{R} > p$$





Remark: the long run behavior of the economy is driven by the endogenous volatility.

Application: Minimum Capital Ratio

- What happens if banks are subject to a minimal Capital Ratio (CR) Λ?

$$\boxed{e_t \geq \Lambda k_t}$$

- Maximization problem of an individual bank:

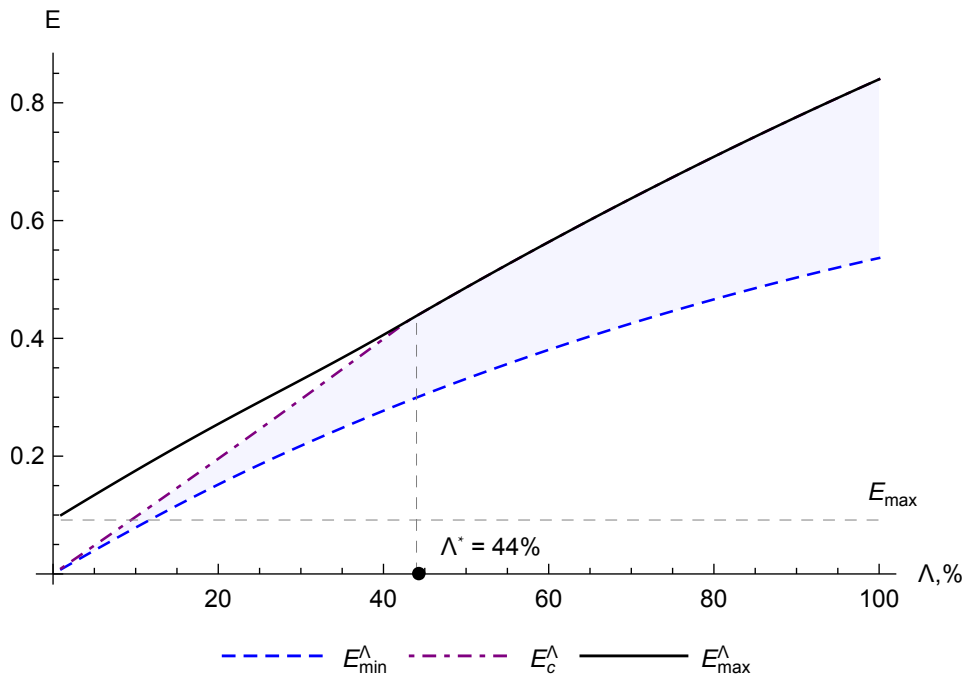
$$v_\Lambda(e, E) = \max_{k_t \leq \frac{e}{\Lambda}, d\delta_t, di_t} \mathbb{E}\left[\int_0^{+\infty} e^{-\rho t}\left(d\delta_t - (1+\gamma)di_t\right)\right]$$

- Homogeneity property is preserved:

$$v_\Lambda(e, E) \equiv e u_\Lambda(E)$$

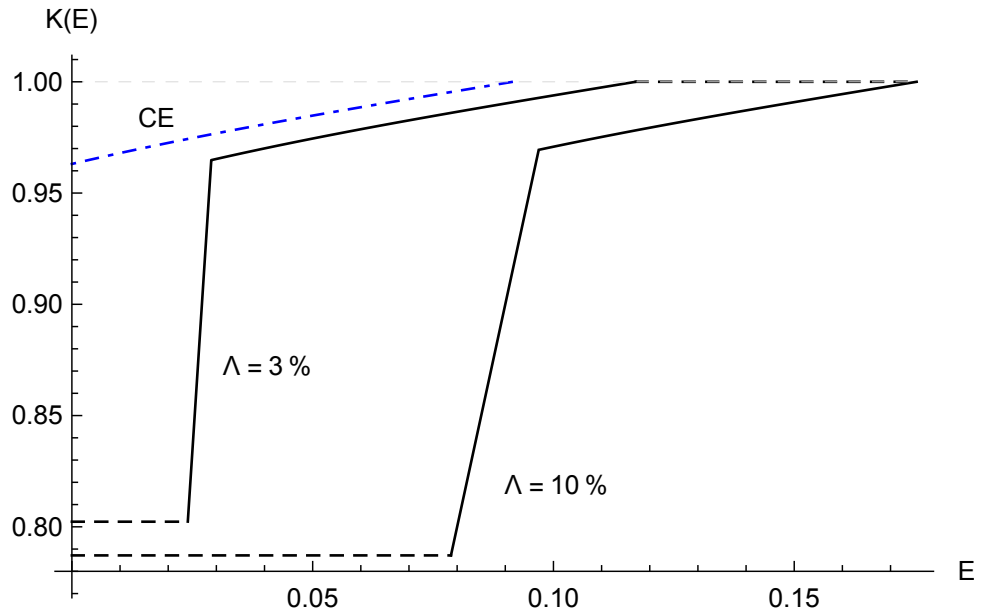
- We find that CR constraint binds for low E and is slack for high E.
- $u_\Lambda(.)$ and equilibrium loan rate $R_\Lambda(.)$ have different expressions in constrained $(\boldsymbol{E < E_c^\Lambda})$ and unconstrained $(\boldsymbol{E \geq E_c^\Lambda})$ regions.

CAPITAL RATIO AND BANK POLICIES



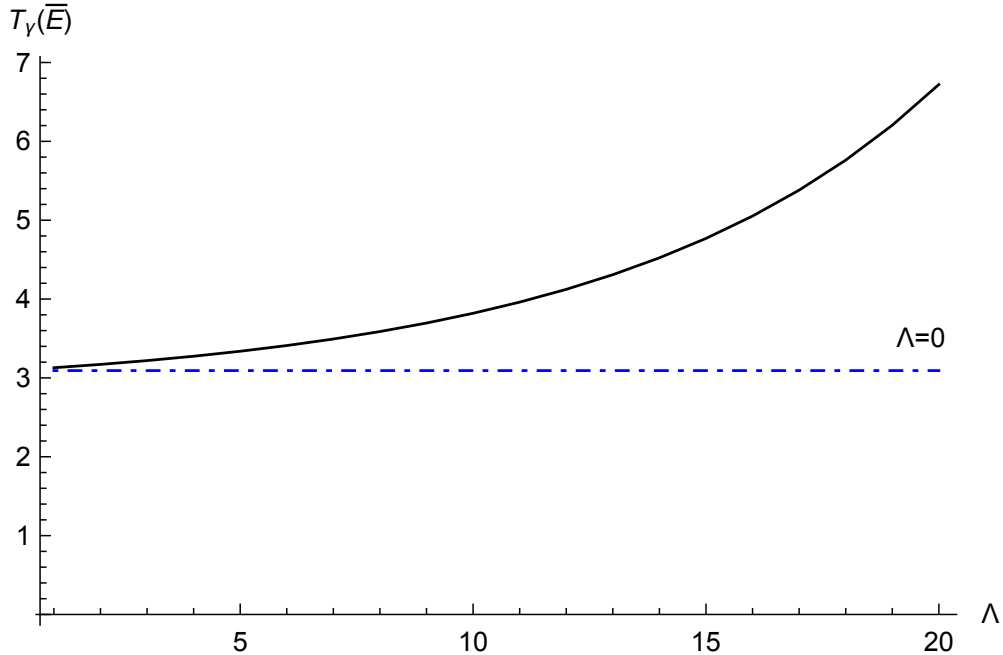
- Banks increase their target level of capital ($E^{\Lambda}_{max} > E_{max}$) and recapitalize earlier ($E^{\Lambda}_{min} > 0$).
- Small and moderate Λ: both the unconstrained and constrained regimes co-exist.
- Very high Λ: the unconstrained region disappears (no extra capital cushions).

Capital ratio and lending



- Banks reduce lending not only in the constrained region, but also in the unconstrained one
- Lending $\downarrow \Rightarrow$ exposure to aggregate shocks $\downarrow \Rightarrow$ endogenous volatility $\downarrow$

EXPECTED TIME TO RECAPITALIZATION



- **Stability measure:** $T_\gamma(\overline{E})$ - the average time to recapitalization starting from the average level of aggregate capital $\overline{E}$
- $\Lambda \uparrow \Rightarrow$ endogenous volatility $\downarrow$ + expected banks' profits $\uparrow \Rightarrow$ stability $\uparrow$

Conclusion

- Tractable dynamic macro model where aggregate bank capital drives credit volume.
- Asymptotic behavior described by the ergodic distribution.
- Model permits simple analysis of macro-prudential policy.
- Further investigations: market activities complementary to lending, endogenous risk-taking, banks' defaults.

Thank you!