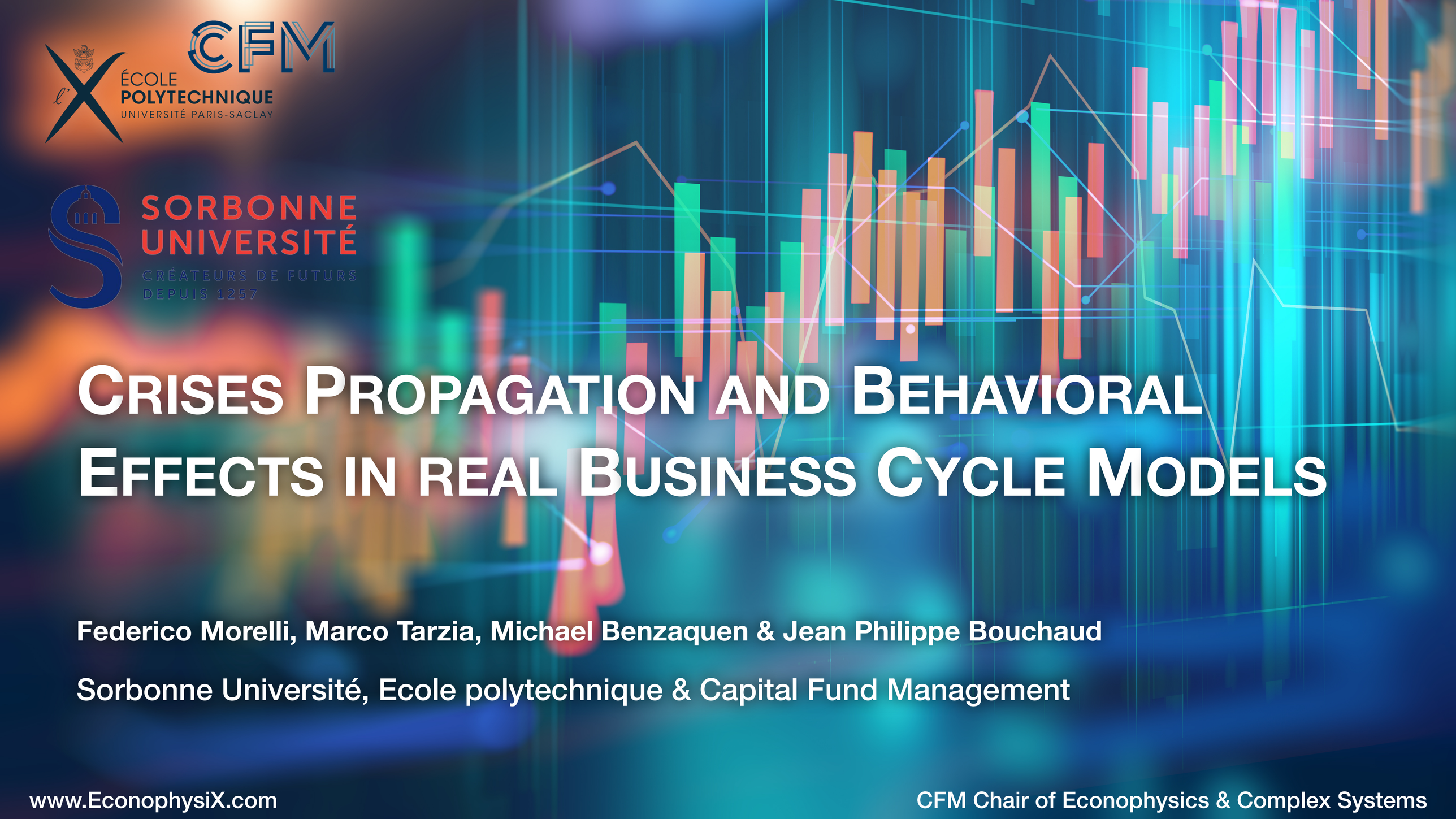

Crises Propagation and Behavioral Effects in real Business Cycle Models

Federico Morelli, Marco Tarzia, Michael Benzaquen & Jean Philippe Bouchaud

Sorbonne Université, Ecole polytechnique & Capital Fund Management

FIRST PART - INTRODUCTION

SOME INSIGHTS OF ECONOMIC THEORY

SECOND PART - RESULTS

CONFIDENCE COLLAPSE IN A PROTO-DSGE MODEL[*]

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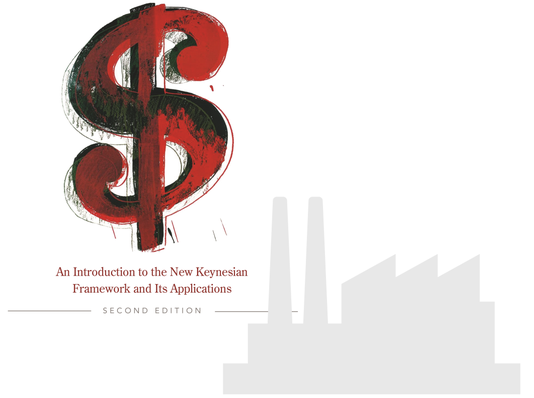
DYNAMIC STOCHASTIC GENERAL EQUILIBRIUM (DSGE)[*]

AIMED AT DESCRIBING THE **REAL BUSINESS CYCLE**

DSGE MODELS ARE BASED ON 4 MAIN **AXIOMS**

GENERAL EQUILIBRIUM EXOGENOUS SHOCK

REPRESENTATIVE AGENT FULL RATIONALITY



A REPRESENTATIVE HOUSEHOLD

A REPRESENTATIVE FIRM

CENTRAL BANK

TO DETERMINE MACRO ECONOMICAL VARIABLES (*CONSUMPTION, WORKING HOURS*….)

AND THEIR DEPENDENCE ON **EXTERNAL SHOCK**

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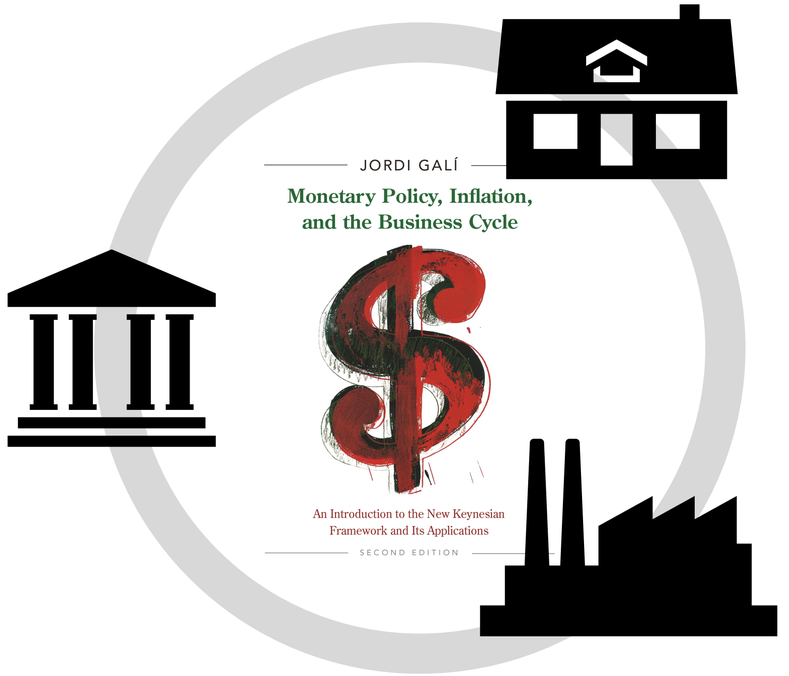

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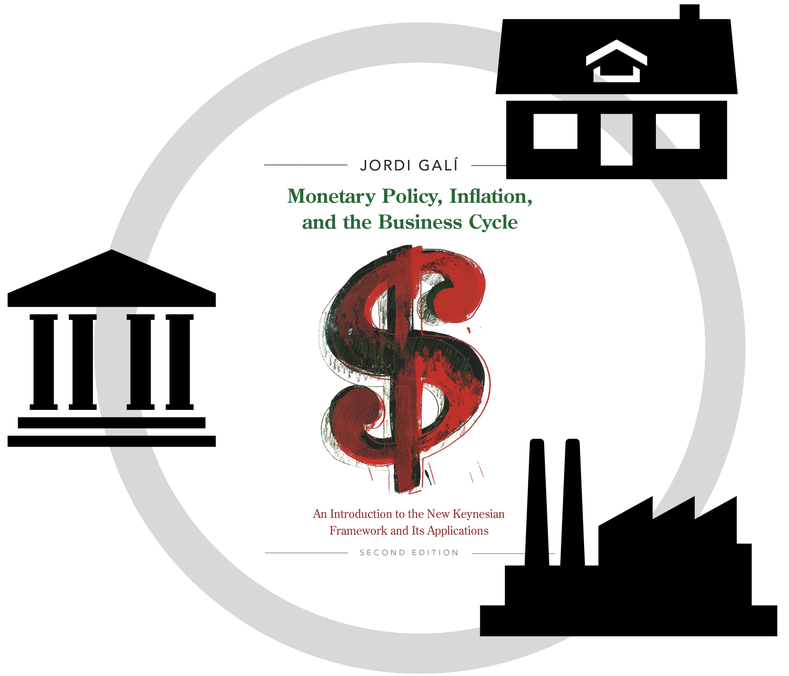

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The representative Household

Every time period the infinitely living representative household (RA)

Consumes C_t of goods and **provides** N_t **working hours** to the firm.

Utility function : $U_t = \log C_t - \gamma (N_t)^2$

Budget constraint : $C_t + \frac{B_t}{1+r_t} = \frac{B_{t-1}}{1+\pi_t} + u_t N_t$

Utility Function

Budget Constraint

The representative Household

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Utility Function

Budget Constraint

THE RA MAXIMIZES ITS **EXPECTED UTILITY**, OVER AN INFINITE TIME HORIZON

$$\max_{\{C_t,N_t,B_t,\lambda_t\}} \mathbb{E}_t \left[\sum_{t'=0}^{\infty} \beta^{t'} \left\{ U(C_{t'}, N_{t'}) + \lambda_{t'} \left(C_{t'} + \frac{B_{t'}}{(1+r_{t'})} - u_{t'} N_{t'} - \frac{B_{t'-1}}{1+\pi_{t'}} \right) \right\} \right]$$

DISCOUNT FACTOR

HOUSEHOLD STATE EQUATION : $C_t N_t = \frac{u_t}{\gamma}$

UTILITY FUNCTION

BUDGET CONSTRAINT

STATE EQUATION

The representative Household

The RA maximizes its **expected utility**, over an infinite time horizon

$$\max_{\{C_t,N_t,B_t,\lambda_t\}} \mathbb{E}_t \left[\sum_{t'=0}^{\infty} \beta^{t'} \left\{ U(C_{t'}, N_{t'}) + \lambda_{t'} \left(C_{t'} + \frac{B_{t'}}{(1+r_{t'})} - u_{t'} N_{t'} - \frac{B_{t'-1}}{1+\pi_{t'}} \right) \right\} \right]$$

Household state Equation : $C_t N_t = \frac{u_t}{\gamma}$

Utility Function

Budget Constraint

State Equation

The representative Firm

Every period the **Representative Firm** produces Y_t and computes its real profit $\mathbb{P}_t / p_t$

Production function : $Y_t = z_t \, N_t^{1-\alpha}/(1-\alpha)$

Profit function : $\mathbb{P}_t / p_t = Y_t - u_t N_t$

z_t: Technology at time t

Random autocorrelated variable (Ornstein Uhlenbeck)

(Exogenous Shock)

Production Function

Profit Maximisation

Real Wages

The representative Firm

Every period the **Representative Firm** produces Y_t and computes its real profit $\mathbb{P}_t / p_t$

Production function : $Y_t = z_t \, N_t^{1-\alpha}/(1-\alpha)$

Profit function : $\mathbb{P}_t / p_t = Y_t - u_t N_t$

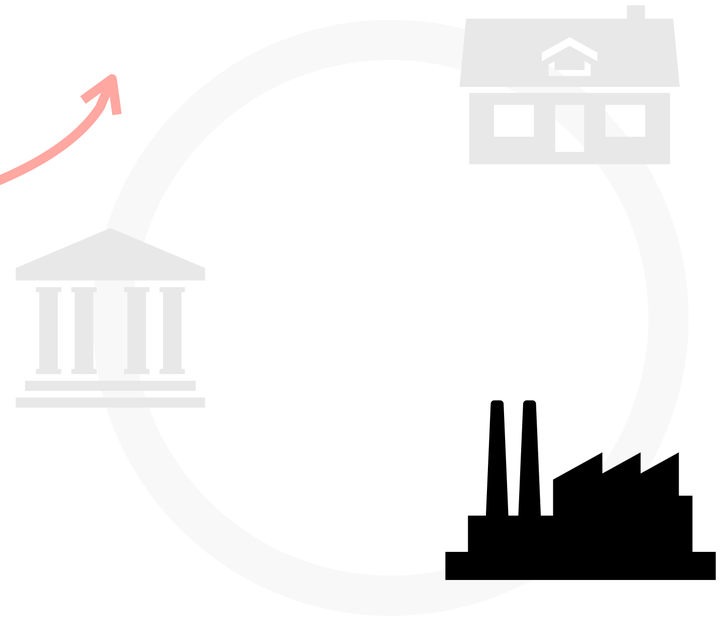
Profit maximisation : $\partial_{N_t} \mathbb{P}_t / p_t = 0$

Technology at time t

Random autocorrelated variable (Ornstein Uhlenbeck)

(Exogenous Shock)

The **maximisation** leads to **real wages** $u_t \equiv u_t(z_t)$



Production Function

Profit Maximisation

Real Wages

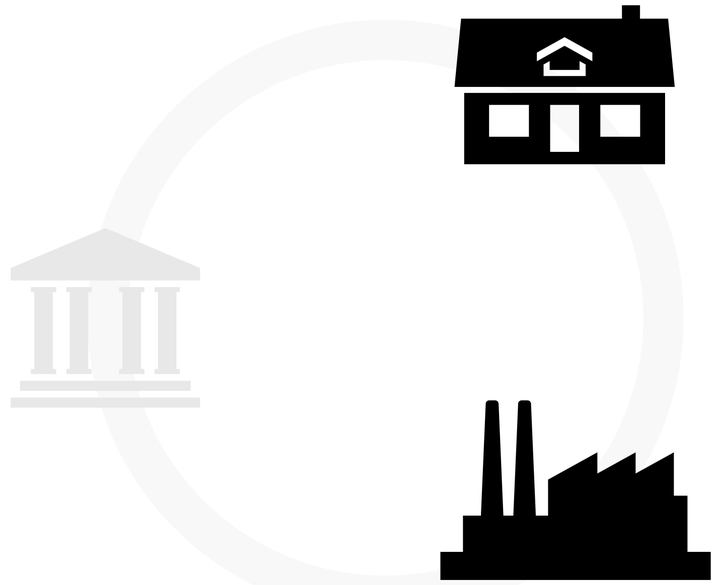
EVERY PERIOD THE **REPRESENTATIVE FIRM** PRODUCES Y_t AND COMPUTES ITS REAL PROFIT $\mathbb{P}_t/p_t$

PRODUCTION FUNCTION : $Y_t = z_t \cdot N_t^{1-\alpha}/(1-\alpha)$

PROFIT FUNCTION : $\mathbb{P}_t/p_t = Y_t - u_t N_t$

PROFIT MAXIMISATION : $\partial_{N_t} \mathbb{P}_t/p_t = 0$

THE **MARKET CLEARS** : $C_t = Y_t$



MARKET CLEARING

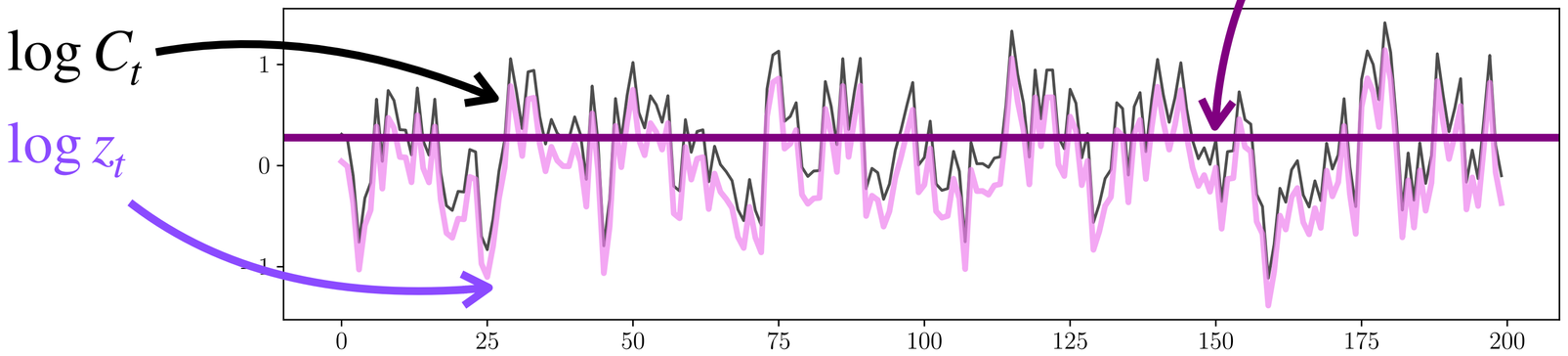
A LINEAR SYSTEM HAVING THREE EQUATIONS AND THREE UNKNOWNS HAS A **UNIQUE SOLUTION** AS A FUNCTION OF THE TECHNOLOGY TERM

STATE EQUATION
REAL WAGES
MARKET CLEARING

CONSUMPTION : $C_t(z_t)$

LABOUR : $N_t(z_t)$

REAL WAGE : $u_t(z_t)$



DYNAMIC STOCHASTIC GENERAL EQUILIBRIUM MODELS

ARE **"BUSINESS AS USUAL"** MODELS

NOT DEVELOPED TO PREDICT THE CRISES NOR TO DEAL WITH CRISES

(DEVELOPED PRIOR TO THE 2008 GFC)

CANNOT, BY DESIGN, ACCOMODATE BIG ENDOGENOUS EVENTS

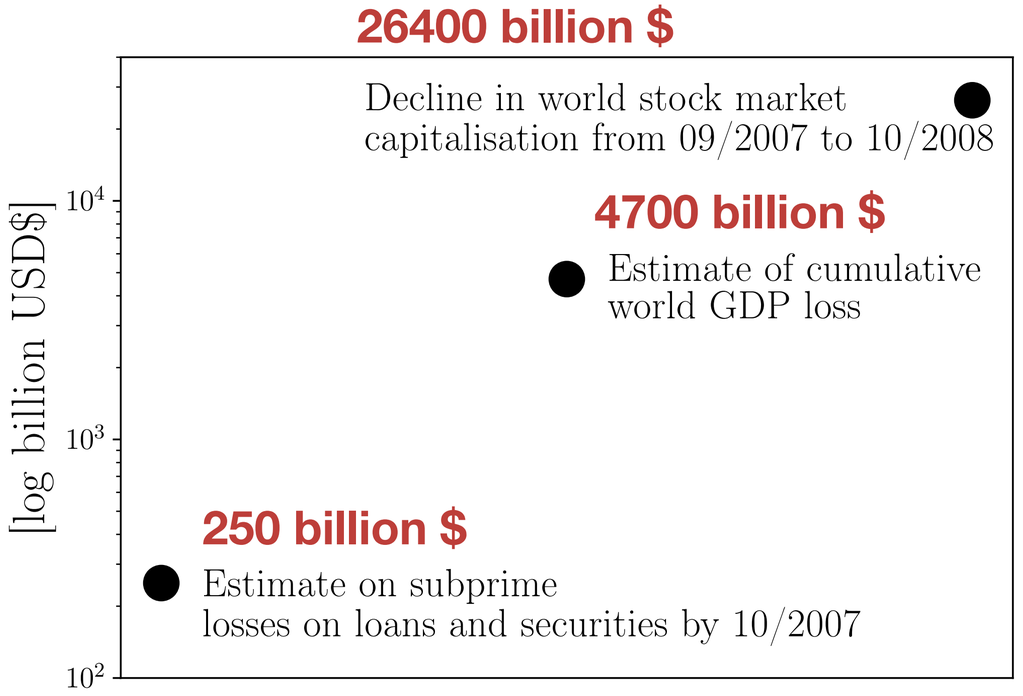
"LARGE SHOCKS, LARGE BUSINESS CYCLE"

THE **2008 SUBPRIME CRISES**

WAS A RELATIVELY SMALL SHOCK COMPARED TO

THE **OVERALL DECLINE IN THE WORLD STOCK MARKET**

"SMALL SHOCKS, LARGE BUSINESS CYCLE"



THE 2008 **GLOBAL FINANCIAL CRISIS**

LEFT A BIG VOID IN THE THEORETICAL MACROECONOMICS MODELING

*"WE IN THE FIELD DID THINK OF THE ECONOMY AS **ROUGHLY LINEAR**, CONSTANTLY SUBJECT TO DIFFERENT SHOCKS, CONSTANTLY FLUCTUATING, BUT **NATURALLY RETURNING TO EQUILIBRIUM OVER TIME**. [...]. THE PROBLEM IS THAT WE CAME TO BELIEVE THAT THIS WAS INDEED THE WAY THE WORLD WORKED."*

OLIVIER BLANCHARD, FORMER CHIEF ECONOMIST OF THE IMF

WHAT WAS THE **ECONOMISTS' REACTION** TO THE GFC ?

DSGE

WORKED TO ADD FEATURES THAT WERE MISSING TO THE ORIGINAL MODELS

HETEROGENEITIES HANK TANK

FINANCIAL MARKETS

ABM

AGENT BASED MODELS

NEW CLASS OF ECONOMISTS SEEKS **RADICAL CHANGE IN THE PARADIGM**

COMPUTATIONAL MODELS AIMED AT DESCRIBING LARGE SYSTEMS/SOCIETIES/ECONOMIES STARTING FROM THE BEHAVIORS AND INTERACTIONS OF INDIVIDUALS

WHAT WAS THE **ECONOMISTS' REACTION** TO THE GFC ?

DSGE

REPRESENTATIVE AGENT

FULL RATIONAL AGENT, **UTILITY MAXIMIZER**

GENERAL EQUILIBRIUM MODELS

SHOCKS ARE PURELY **EXOGENOUS**

EASY TO ACCOMODATE **FORWARD LOOKING-NESS**

WORKHORSE FOR CENTRAL BANKS

REPRESENTATIVE AGENT MODELS

ABM

INTERACTING AND HETEROGENEOUS **MULTI-AGENTS**

DIFFERENT LEVELS OF AWARENESS

OUT OF EQUILIBRIUM MODELS

BOTH **EXOGENOUS** AND **ENDOGENOUS** SHOCKS

HARD ACCOMODATE **FORWARD LOOKING-NESS**

NEW TOOL FOR MACROECONOMIC ANALYSIS

EASILY ADAPTED TO TAKE IN ACCOUNT
HETEROGENEITIES & INTERACTIONS

WHAT WAS THE **ECONOMISTS' REACTION** TO THE GFC ?

DSGE

REPRESENTATIVE AGENT

FULL RATIONAL AGENT, **UTILITY MAXIMIZER**

GENERAL EQUILIBRIUM MODELS

SHOCKS ARE PURELY **EXOGENOUS**

EASY TO ACCOMODATE **FORWARD LOOKING-NESS**

WORKHORSE FOR CENTRAL BANKS

FULLY RATIONAL AGENTS MAXIMIZING A UTILITY FUNCTION

ABM

INTERACTING AND HETEROGENEOUS **MULTI-AGENTS**

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NEW TOOL FOR MACROECONOMIC ANALYSIS

A PRIORI NO **ASSUMPTION** OVER RATIONALITY

WHAT WAS THE **ECONOMISTS' REACTION** TO THE GFC ?

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SINGLE EQUILIBRIUM LINEARIZED MODELS

ABM

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HARD ACCOMODATE **FORWARD LOOKING-NESS**

NEW TOOL FOR MACROECONOMIC ANALYSIS

DO NOT SEEK **EQUILIBRIUM**

WHAT WAS THE **ECONOMISTS' REACTION** TO THE GFC ?

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REPRESENTATIVE AGENT

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GENERAL EQUILIBRIUM MODELS

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EASY TO ACCOMODATE **FORWARD LOOKING-NESS**

WORKHORSE FOR CENTRAL BANKS

"LARGE SHOCKS, LARGE BUSINESS CYCLE"

ABM

INTERACTING AND HETEROGENEOUS **MULTI-AGENTS**

DIFFERENT LEVELS OF AWARENESS

OUT OF EQUILIBRIUM MODELS

BOTH **EXOGENOUS** AND **ENDOGENOUS** SHOCKS

HARD ACCOMODATE **FORWARD LOOKING-NESS**

NEW TOOL FOR MACROECONOMIC ANALYSIS

"SMALL SHOCKS, LARGE BUSINESS CYCLE"

WHAT WAS THE **ECONOMISTS' REACTION** TO THE GFC ?

DSGE

REPRESENTATIVE AGENT

FULL RATIONAL AGENT, **UTILITY MAXIMIZER**

GENERAL EQUILIBRIUM MODELS

SHOCKS ARE PURELY **EXOGENOUS**

EASY TO ACCOMODATE **FORWARD LOOKING-NESS**

WORKHORSE FOR CENTRAL BANKS

REPRESENTATIVE AGENT IS **FORWARD-LOOKING**

ABM

INTERACTING AND HETEROGENEOUS **MULTI-AGENTS**

DIFFERENT LEVELS OF AWARENESS

OUT OF EQUILIBRIUM MODELS

BOTH **EXOGENOUS** AND **ENDOGENOUS** SHOCKS

HARD ACCOMODATE **FORWARD LOOKING-NESS**

NEW TOOL FOR MACROECONOMIC ANALYSIS

PSEUDO **FORWARD LOOKING-NESS**

WHAT WAS THE **ECONOMISTS' REACTION** TO THE GFC ?

DSGE

REPRESENTATIVE AGENT

FULL RATIONAL AGENT, **UTILITY MAXIMIZER**

GENERAL EQUILIBRIUM MODELS

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EASY TO ACCOMODATE **FORWARD LOOKING-NESS**

WORKHORSE FOR CENTRAL BANKS

WORKHORSE FOR MONETARY POLICY

ABM

INTERACTING AND HETEROGENEOUS **MULTI-AGENTS**

DIFFERENT LEVELS OF AWARENESS

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BOTH **EXOGENOUS** AND **ENDOGENOUS** SHOCKS

HARD ACCOMODATE **FORWARD LOOKING-NESS**

NEW TOOL FOR MACROECONOMIC ANALYSIS

RECENTLY INTRODUCED AS A TOOL FOR MACRO ECONOMIC ANALYSIS

WHAT WAS THE **ECONOMISTS' REACTION** TO THE GFC ?

DSGE

- **REPRESENTATIVE AGENT**
- FULL RATIONAL AGENT, **UTILITY MAXIMIZER**
- **GENERAL EQUILIBRIUM** MODELS
- SHOCKS ARE PURELY **EXOGENOUS**
- EASY TO ACCOMODATE **FORWARD LOOKING-NESS**
- **WORKHORSE** FOR CENTRAL BANKS

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HOW TO **BRIDGE THE GAP?**

STARTING FROM THE BASELINE **DSGE** MODEL

WE RELAX ITS AXIOMS

~~REPRESENTATIVE~~ MULTI AGENTS

FULL RATIONALITY

EXOGENOUS SHOCK

GENERAL EQUILIBRIUM

HETEROGENEITIES & **INTERACTIONS** TO REPRODUCE COMPLEX BEHAVIOR

P.W. ANDERSON - MORE IS DIFFERENT

STARTING FROM THE BASELINE **DSGE** MODEL

WE RELAX ITS AXIOMS

~~REPRESENTATIVE~~ **MULTI AGENTS**

~~FULL-RATIONALITY~~

EXOGENOUS SHOCK

GENERAL EQUILIBRIUM

ANIMAL SPIRITS AS DRIVERS OF ECONOMIC ACTIVITY

IRRATIONAL BEHAVIORS ARE FUNDAMENTAL FOR THE UNDERSTANDING OF ECONOMICS

CONFIDENCE COLLAPSE AND RISK AVERSIONS

STARTING FROM THE BASELINE **DSGE** MODEL

WE RELAX ITS AXIOMS

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~~FULL-RATIONALITY~~

EXOGENOUS + ENDOGENOUS SHOCKS

GENERAL EQUILIBRIUM

EXOGENOUS SHOCKS PROPAGATE **ENDOGENOUSLY**

NON LINEARITIES AMPLIFY THE INPUT SHOCKS

MILD CHANGES OF **THE PARAMETERS** MIGHT HAVE DRAMATIC EFFECTS

STARTING FROM THE BASELINE **DSGE** MODEL

WE RELAX ITS AXIOMS

~~REPRESENTATIVE~~ MULTI AGENTS

~~FULL-RATIONALITY~~

EXOGENOUS + ENDOGENOUS SHOCKS

MULTIPLE ~~GENERAL~~ EQUILIBRIA ~~UM~~

FEEDBACK ECONOMY HAS **MULTIPLE EQUILIBRIA**

PHASE TRANSITIONS AND ECONOMIC RECESSIONS

Bridging the gap using statistical physics

- **More is different** : overcome the RA framework
  - **Multi-agents** models
  - Adding **heterogeneities** and **interactions**
- Adding minimum elements : introducing **animal spirits**
  - **Confidence** as a driver of the decision-making process
  - Notion of "**risk aversion**" when investing
- **Phase transitions** : recessions as multiple equilibria
  - Draw phase diagrams charactering the parameter space
- **Non-linearities** : endogenously amplified shocks
  - **Consumption driven** collapses
  - **Supply driven** recessions

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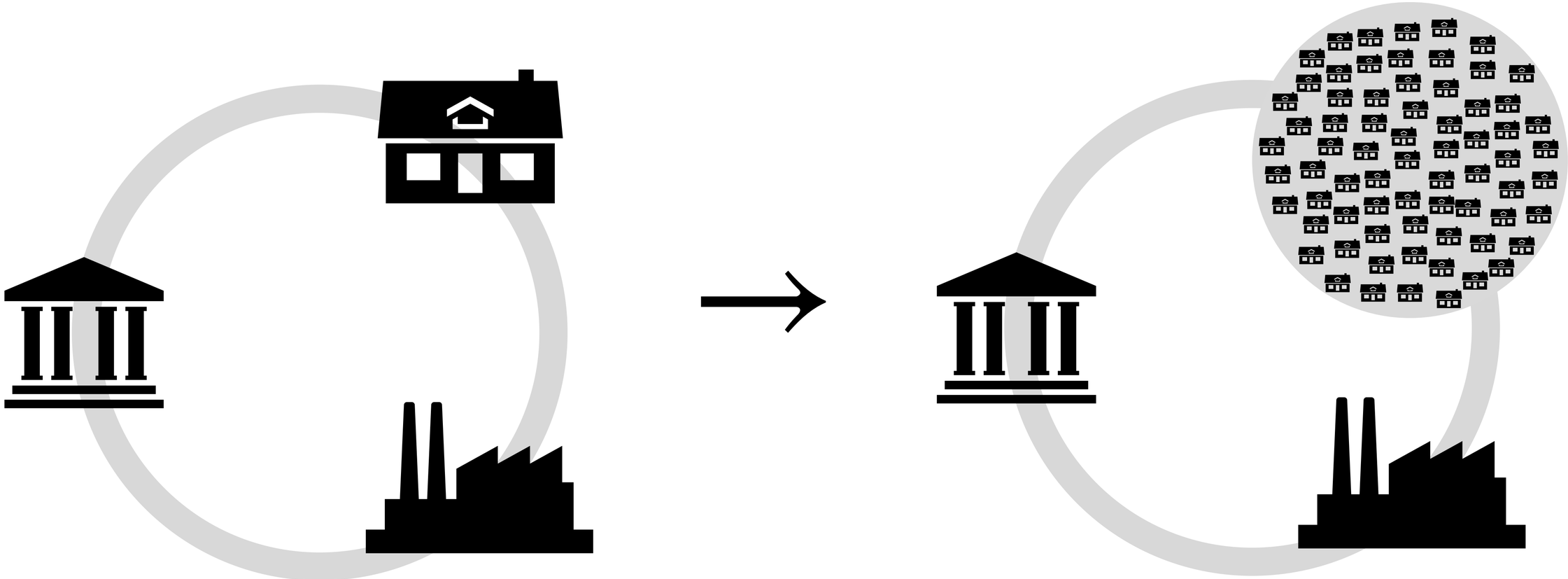
THE **FIRST STEP** TO **BRIDGE THE GAP** WITH ABMS IS TO CONSIDER A DSGE WITH **MANY INTERACTING HOUSEHOLDS**

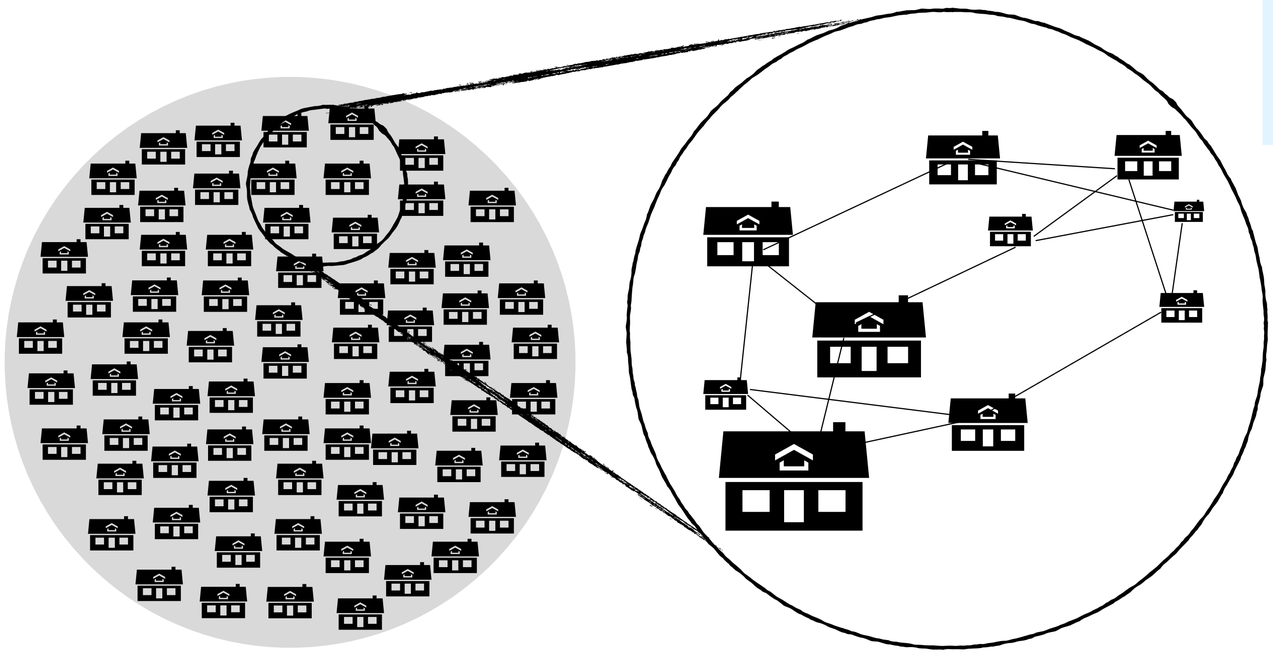
THE ECONOMY DESCRIBED IS RULED BY THE SAME PRINCIPIA



FEEDBACK UTILITY FUNCTION

HOUSEHOLDS ARE THE NODES OF A SOCIAL NETWORK J_{ij} . THEY ESTIMATE THE ECONOMY BY OBSERVING

THE AVERAGE PAST CONSUMPTION OF THEIR NEIGHBORS $\mathcal{N}$



$$U_t^i = f_t^i \cdot \log c_t^i - \gamma \left(n_t^i\right)^2 \ , \qquad f_t^i \to F\left(\sum_{j \in \mathcal{N}(i), j \neq i} J_{ij} \cdot c_{t-1}^j \right)$$

HETEROGENEITIES

INDIVIDUAL PREFERENCES, I.E. $f_t^i = F_t$

SPARSE NETWORK & HETEROGENEITIES

FINITE NUMBER OF HOUSEHOLDS

A Multi-Households model with feedback

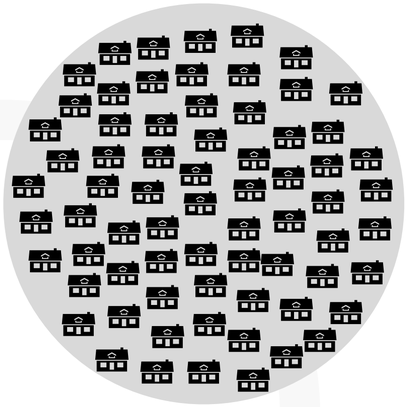
Households maximise their **Utility Function** subject to a **Budget Constraint**

An additional term f_t^i affects the consumption term in the utility

Utility function : $U_t^i = f_t^i \cdot \log c_t^i - \gamma (n_t^i)^2$

Budget constraint : $c_t^i + \frac{b_t^i}{1+r_t} = \frac{b_{t-1}^i}{1+\pi_t} + u_t^i n_t^i$

Feedback State Equation : $c_t^i n_t^i = \frac{f_t^i \cdot u_t^i}{\gamma}$



Utility Function

Budget Constraint

Feedback

State Equation

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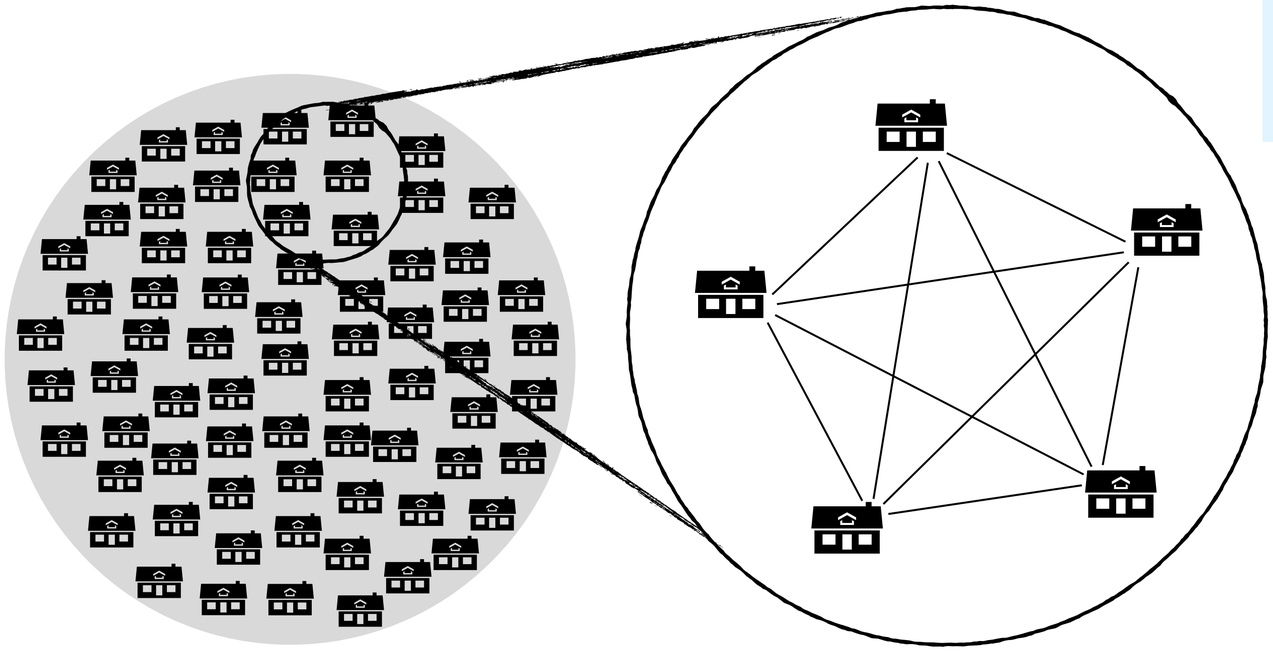

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HOMOGENEOUS LIMIT

SAME PREFERENCES, I.E. $f_t^i = F_t$

FULLY CONNECTED NETWORK, I.E. $J_{ij} = 1/N$

MEAN FIELD - AGGREGATE VARIABLES

THE REPRESENTATIVE FIRM

HIRES LABOUR, **PRODUCES** Y_t AND MAXIMISES ITS REAL **PROFIT FUNCTION** $\mathbb{P}_t/p_t$

PRODUCTION FUNCTION : $Y_t = z_t N_t^{1-\alpha}/(1-\alpha)$

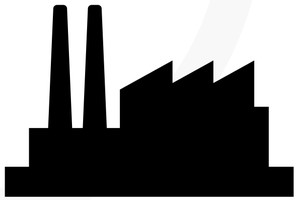
PROFIT FUNCTION : $\mathbb{P}_t/p_t = Y_t - u_t N_t$

PROFIT MAXIMISATION : $\partial_{N_t} \mathbb{P}_t/p_t = 0$

PRODUCTION FUNCTION

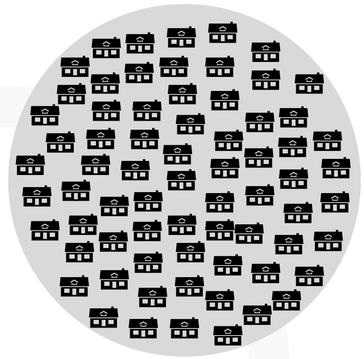
PROFIT MAXIMISATION

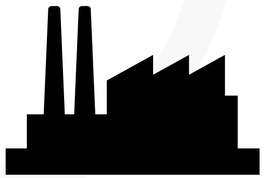
REAL WAGES



THE FEEDBACK ECONOMY

SELF-REFLEXIVE SOLUTION FOR THE **AGGREGATE CONSUMPTION** C_t





FEEDBACK MARKET CLEARING
STATE EQUATION REAL WAGES

MEAN FIELD CONSUMPTION : $C_t = z_t \cdot F^{1/3}(C_{t-1})$

G_t

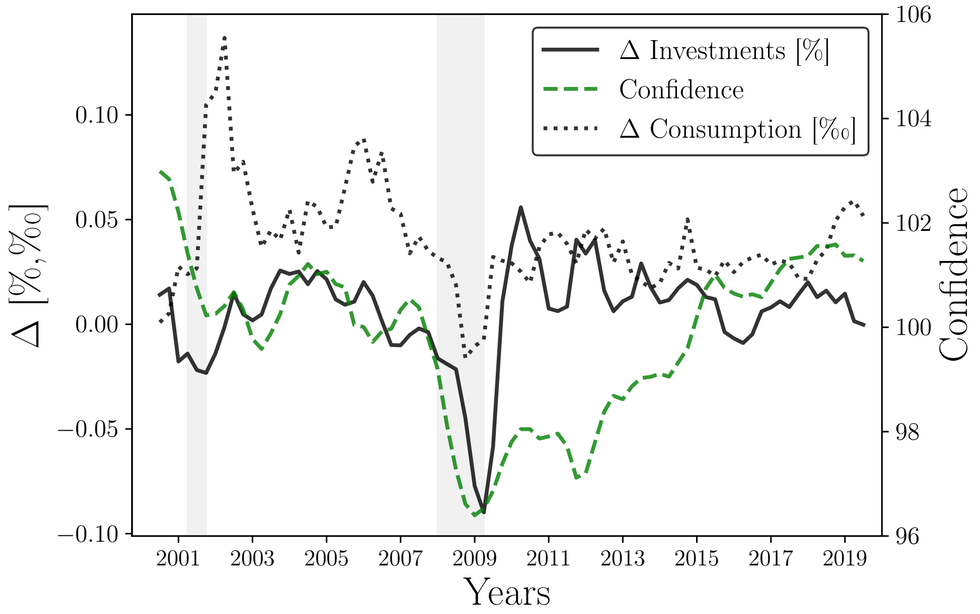
CONFIDENCE AND ITS DEGRADATION PROCESS, I.E. PANIC EFFECTS

THE FEEDBACK $G := F^{1/3}$ MUST TAKE INTO ACCOUNT THE FOLLOWING FACTORS:

WHEN C_t IS **LOW** ECONOMY IS **DEGRADING**

WHEN C_t IS **HIGH** ECONOMY IS **PROSPEROUS**

SHARP CROSSOVER BETWEEN THE TWO STATES



ANY FUNCTIONAL FORMULATION
WITH SIMILAR CHARACTERISTIC WORKS

$$G(c) = \frac{1}{2}\left((c_{\max} - c_{\min}) \cdot \tanh[\theta \cdot (c - c_0)] + c_{\max} + c_{\min}\right)$$

MECHANISMS AKIN TO COOPER, 1988[*] BUT DYNAMICAL. SIMILAR TO KUJ MODELS, BUT RATHER KDJ[**]

[*] R. Cooper [1988]
[**] J. Gali [1994]

EXTERNALITY NOT **MICRO-FOUNDED** BUT RATHER **PLAUSIBLE**

Self-Reflexivity : defining the feedback

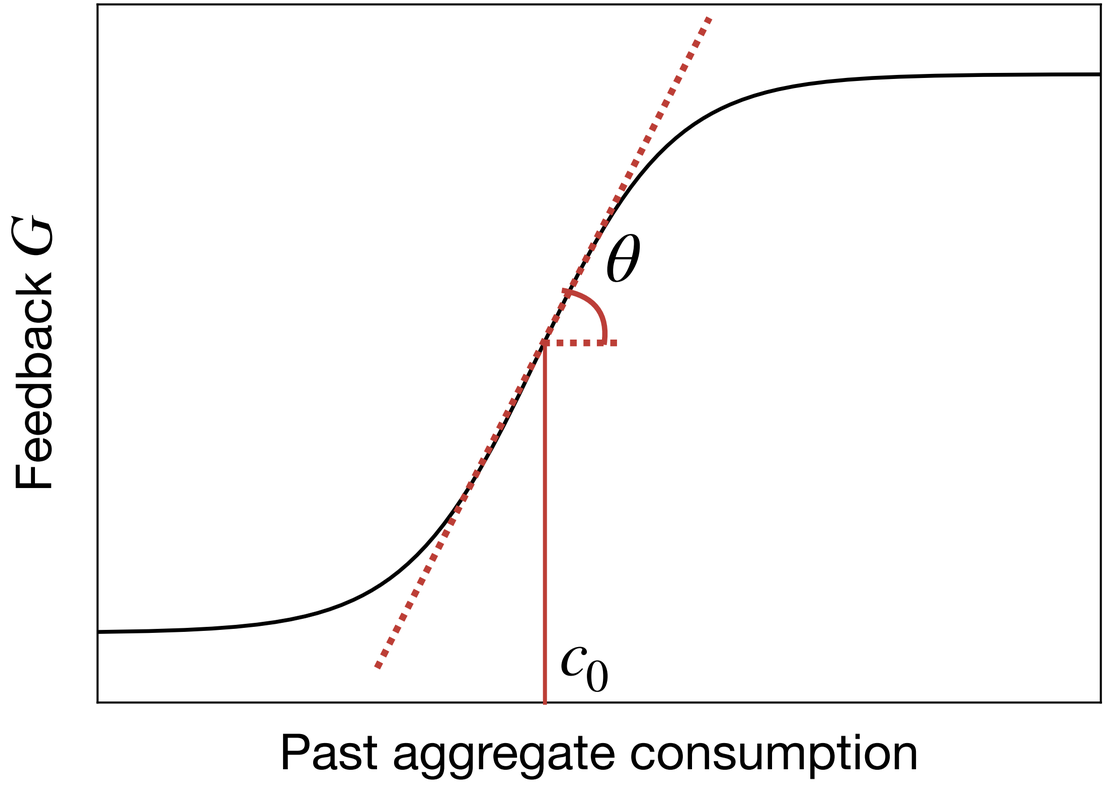
$$G(c) = \frac{1}{2}\left((c_{\max} - c_{\min}) \cdot \tanh[\theta \cdot (c - c_0)] + c_{\max} + c_{\min}\right)$$

θ : people **Sensitivity**

c_0 : **Confidence** threshold

$c_{\max}$: highest consumption level

$c_{\min}$: minimum consumption level



What are the

Equilibrium Solutions?

$$C_t = z_t \cdot G(C_{t-1}) \quad \rightarrow \quad C^* = G(C^*)$$

Equilibrium solutions - Phase A

$$G(c) = \frac{1}{2}\left((c_{\max} - c_{\min}) \cdot \tanh[\theta \cdot (c - c_0)] + c_{\max} + c_{\min}\right)$$

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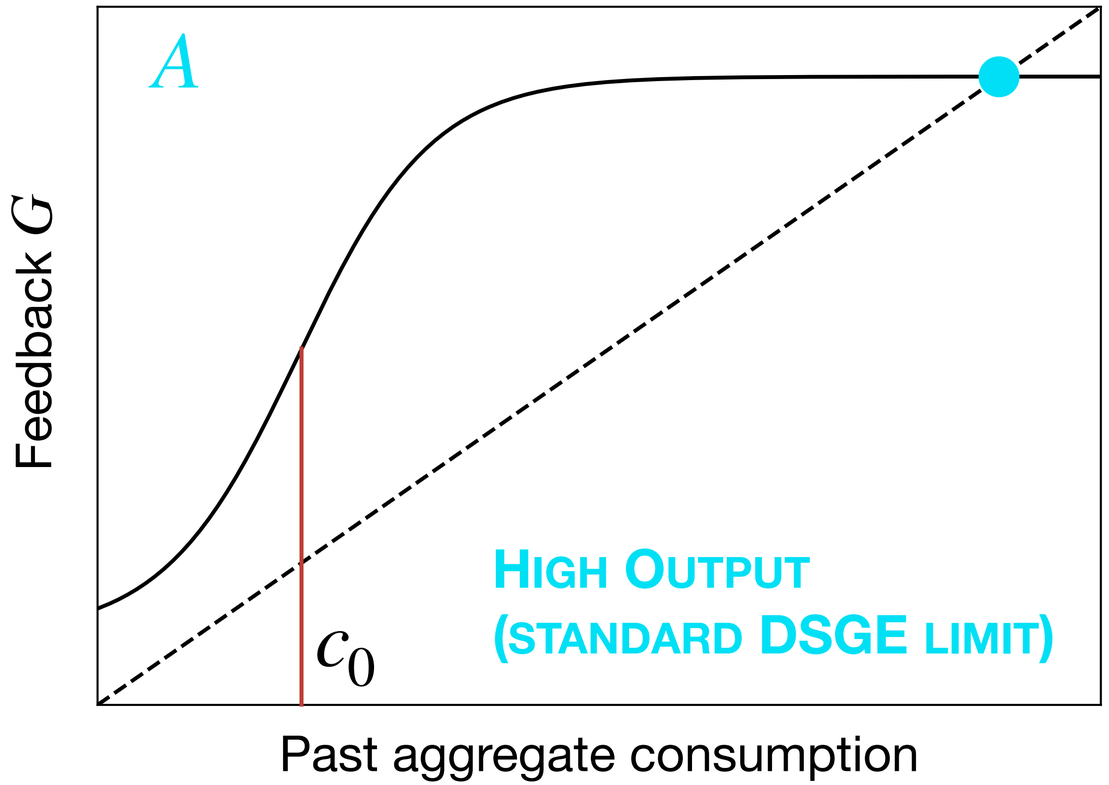

Equilibrium solutions - Phase C

$$G(c) = \frac{1}{2}\left((c_{\max} - c_{\min}) \cdot \tanh[\theta \cdot (c - c_0)] + c_{\max} + c_{\min}\right)$$

θ : people **Sensitivity**

c_0 : **Confidence** threshold

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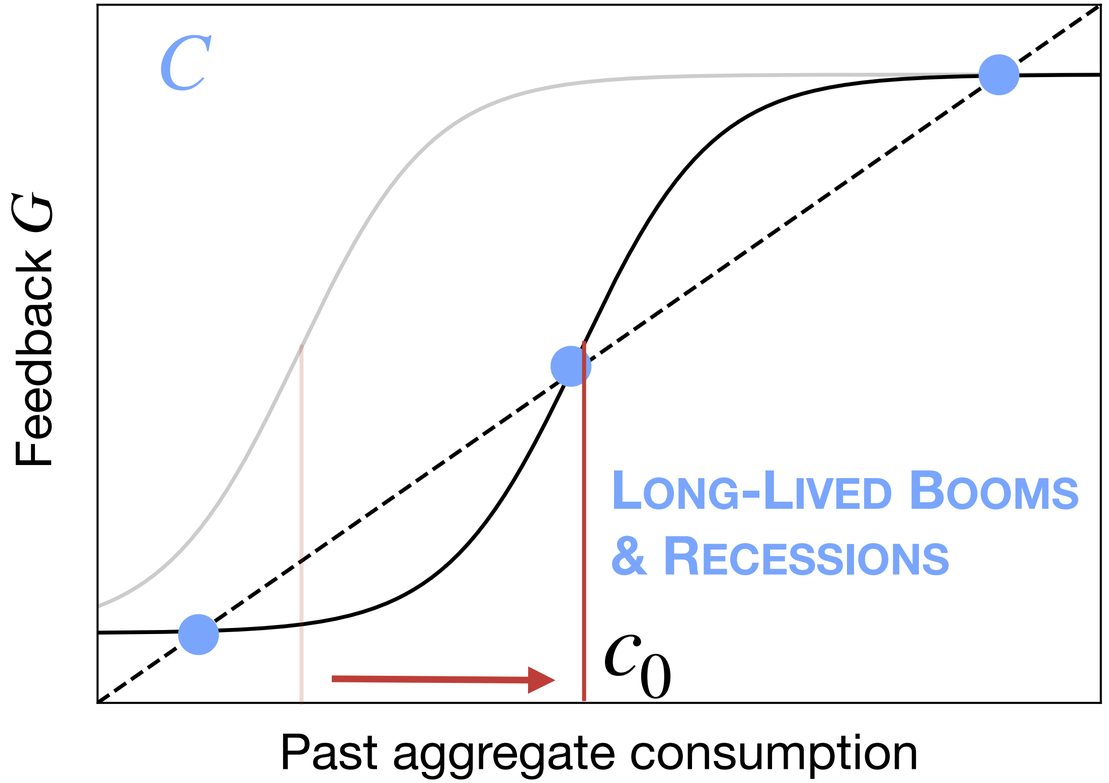

What are the

Equilibrium Solutions?

$$C_t = z_t \cdot G(C_{t-1}) \quad \rightarrow \quad C^* = G(C^*)$$

Equilibrium solutions - Phase B^-

$$G(c) = \frac{1}{2}\left((c_{\max} - c_{\min}) \cdot \tanh[\theta \cdot (c - c_0)] + c_{\max} + c_{\min}\right)$$

θ : people **Sensitivity**

c_0 : **Confidence** threshold

$c_{\max}$: highest consumption level

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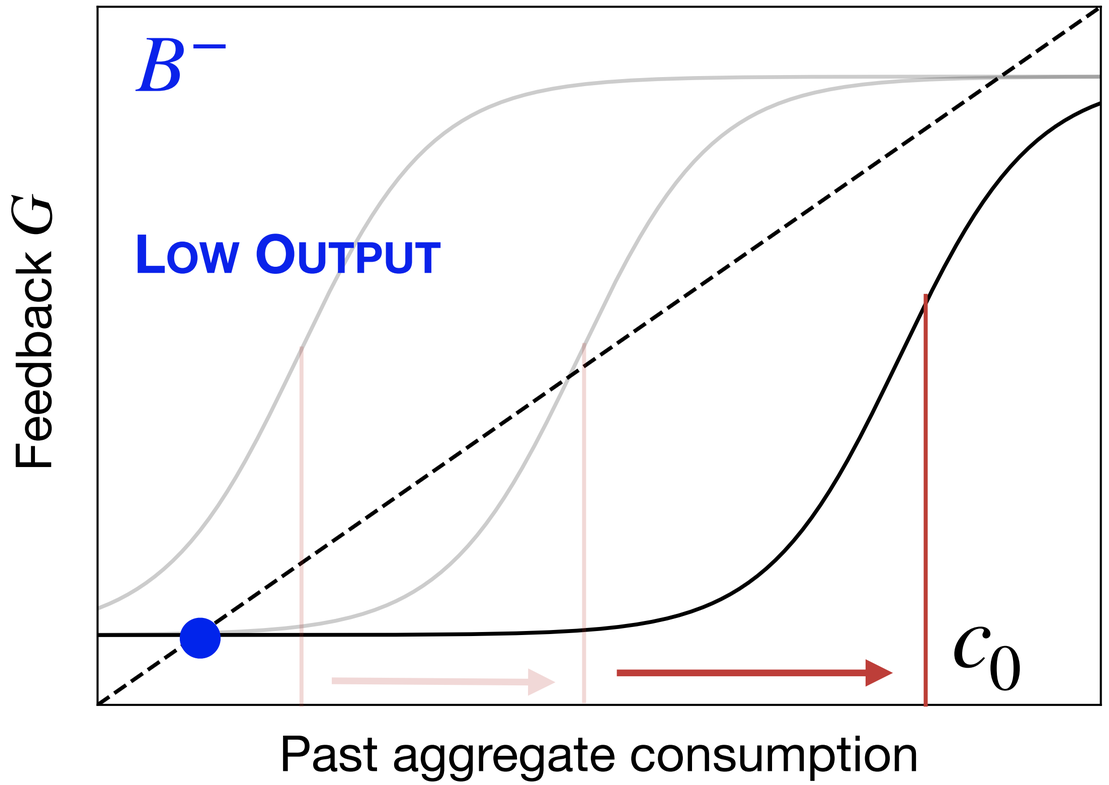


What are the

Equilibrium Solutions?

$$C_t = z_t \cdot G(C_{t-1}) \quad \rightarrow \quad C^* = G(C^*)$$

$$G(c) = \frac{1}{2}\left((c_{\max} - c_{\min}) \cdot \tanh[\theta \cdot (c - c_0)] + c_{\max} + c_{\min}\right)$$

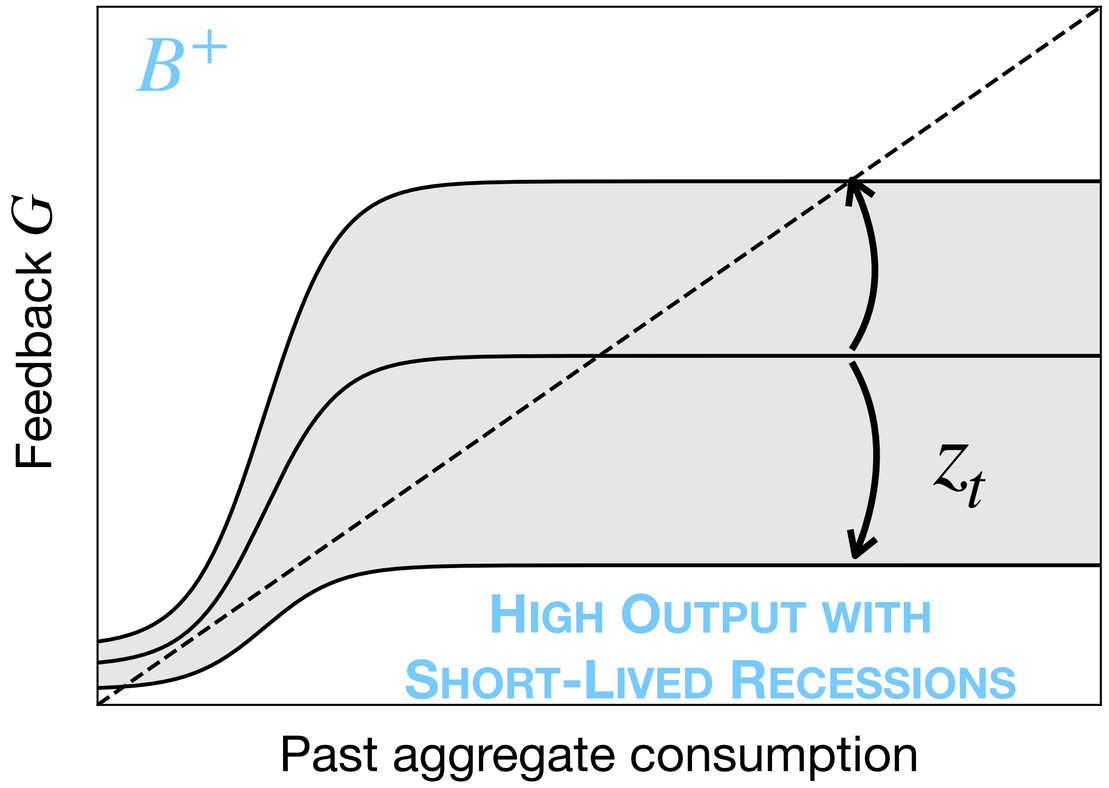
THERE IS AN **ADDITIONAL REGIME**

THE SIGMOID SPANS A STRIPE DEFORMED BY z_t

THE EXOGENOUS NOISE z_t CAN TEMPORARILY INTRODUCE THE THREE FIXED POINT SCENARIO

WHAT ARE THE
EQUILIBRIUM SOLUTIONS?

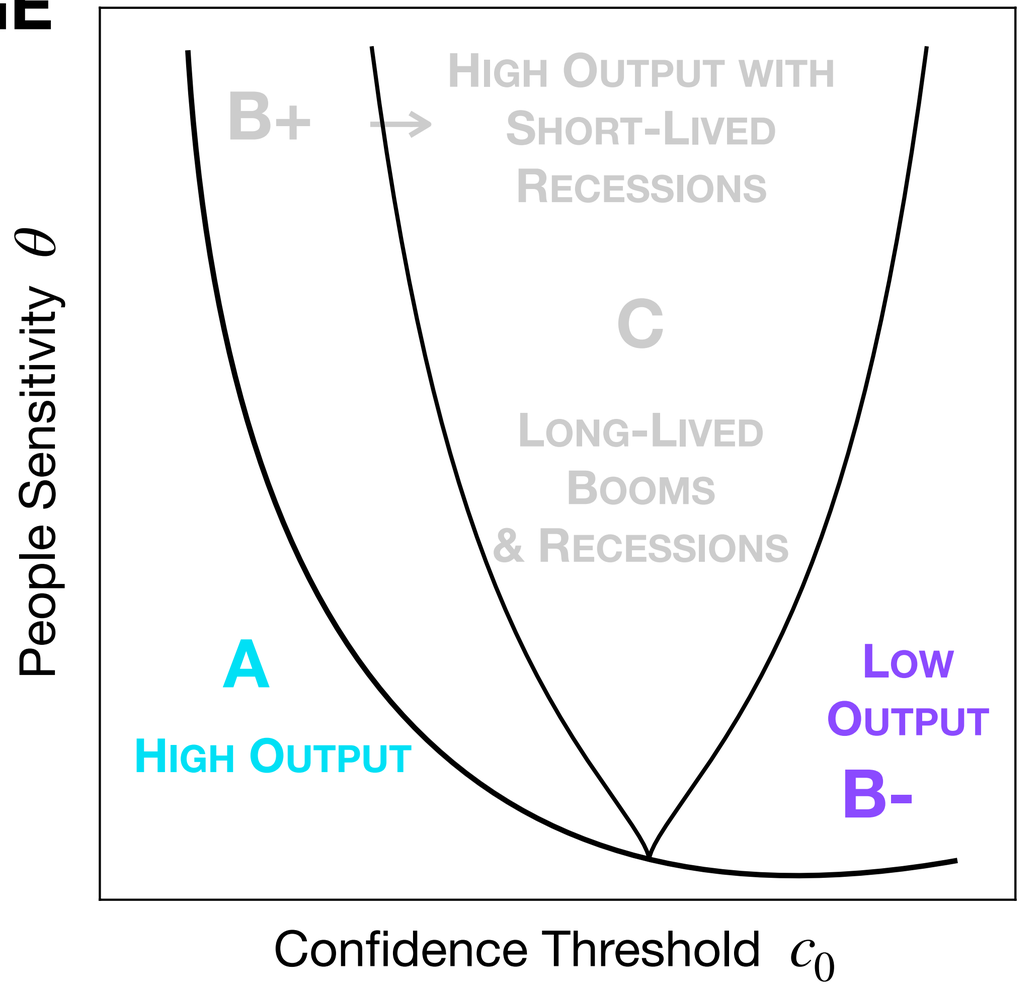
$$C_t = z_t \cdot G(C_{t-1}) \quad \rightarrow \quad C^* = G(C^*)$$



THE PHASE A EQUIVALENT TO THE BASELINE DSGE

THE FEEDBACK MECHANISM LEADS TO AN ENDOGENOUS "EXCESS VOLATILITY " AS SOON AS $G'_> > 1$

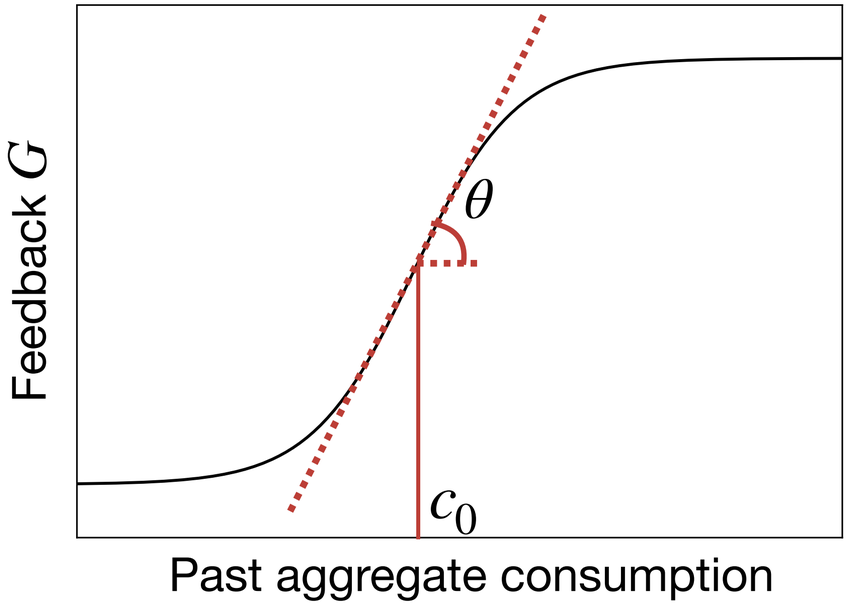
$$\sigma^2 = \frac{\sigma^2}{1 - G'^2_>} \frac{1 + \eta G'_>}{1 - \eta G'_>}, \qquad G'_> := \partial_c G(c)\Big|_{c=c_>}$$



THE PHASE B^- LOW OUTPUT DSGE

VERY RARE MOMENTS OF A PROSPEROUS ECONOMY

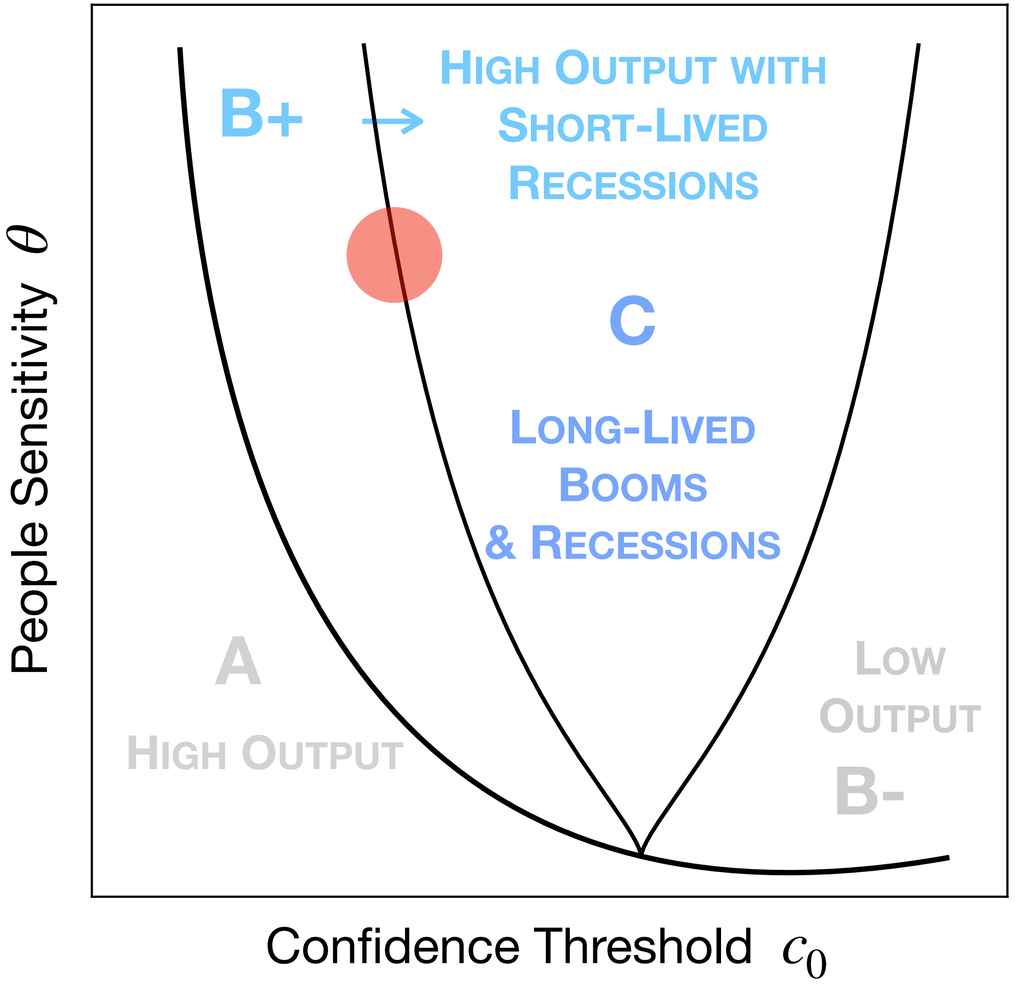
Phase Diagram : $B^+ \rightarrow C$



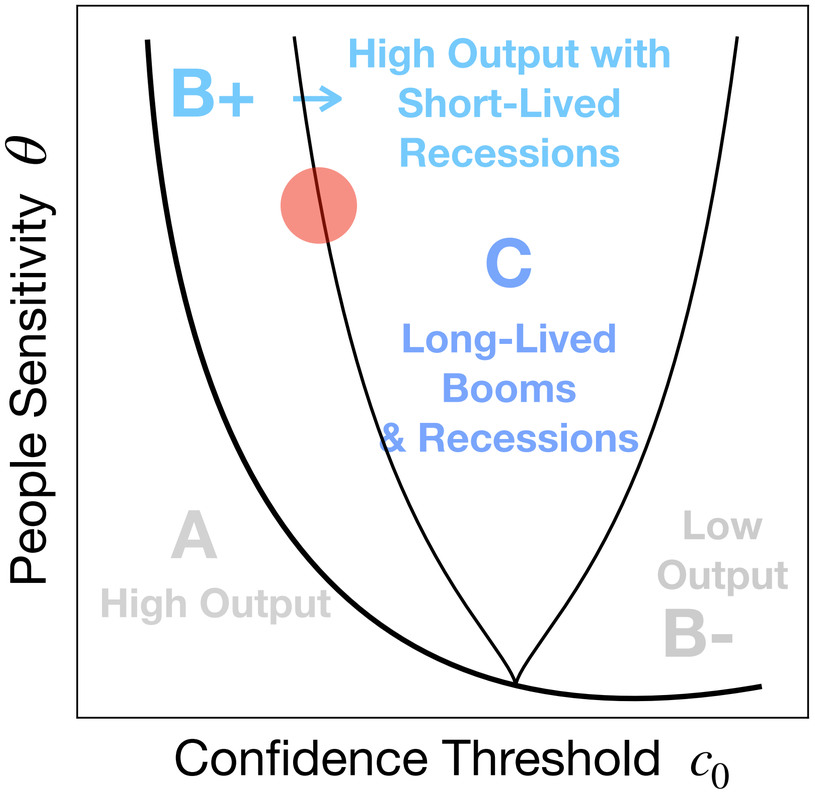
$$C_t = z_t \cdot G(C_{t-1})$$

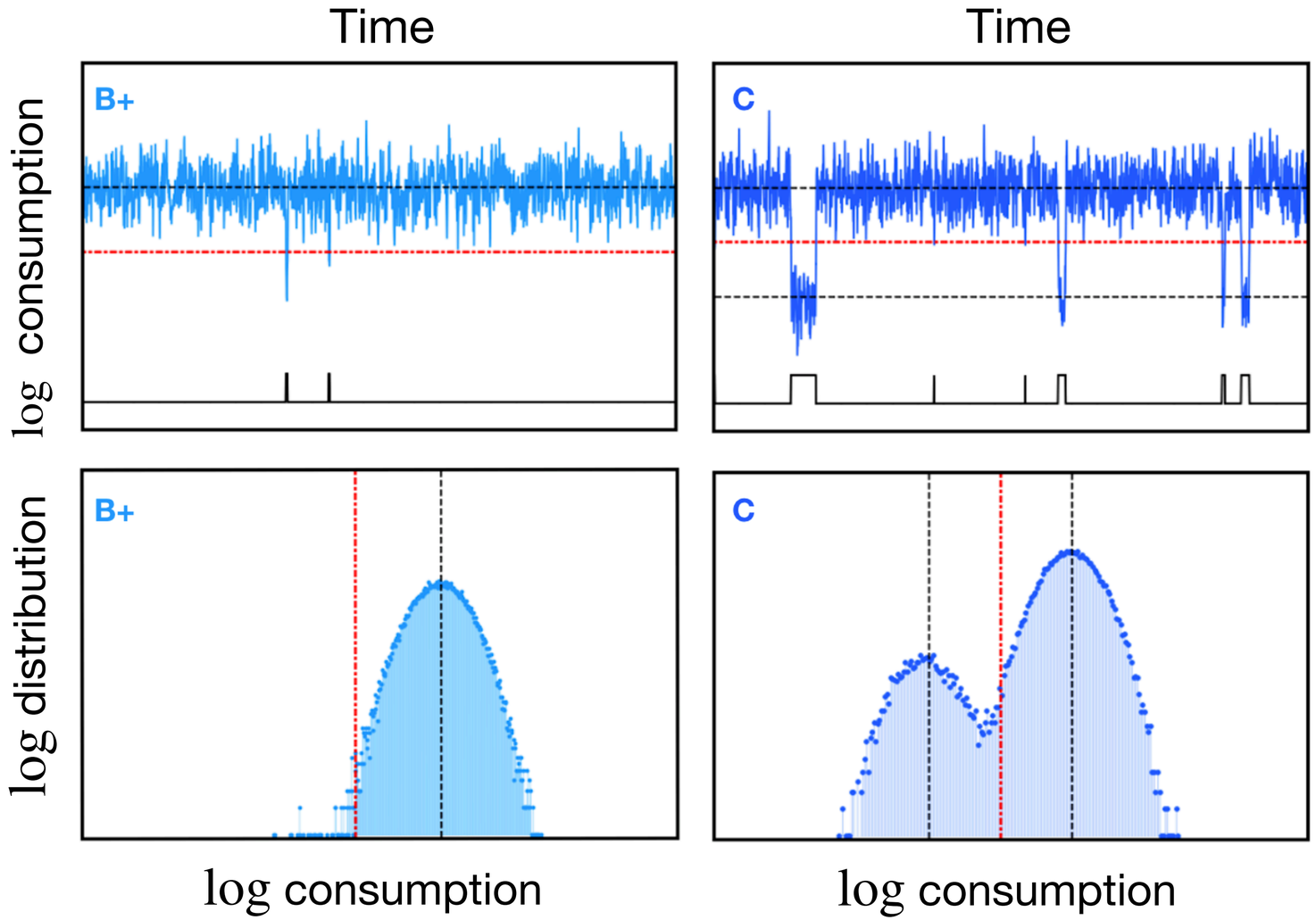
Tipping points

ANY SMALL CHANGE IN THE CONFIDENCE THRESHOLD CAN LEAD TO A PHASE TRANSITION



Feedback economy dynamic

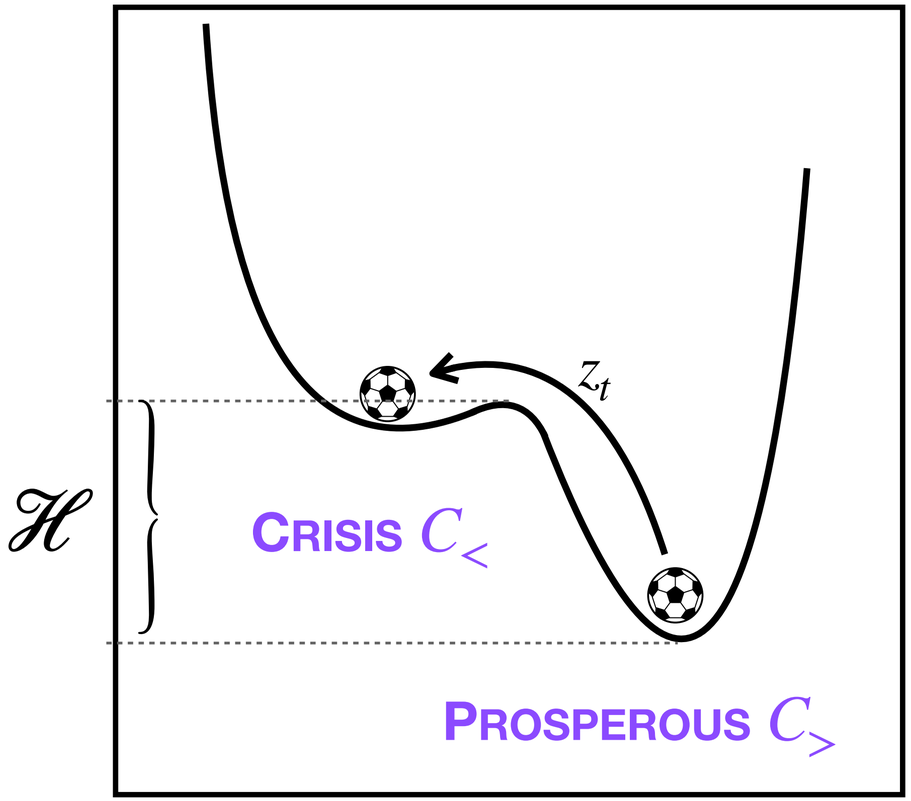




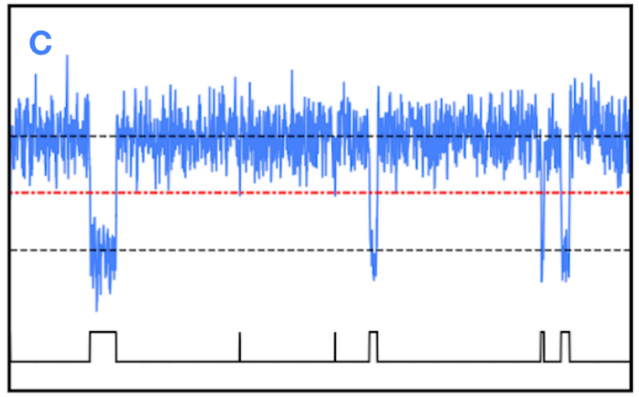
HIGH CONFIDENCE THRESHOLD c_0 LEADS TO A

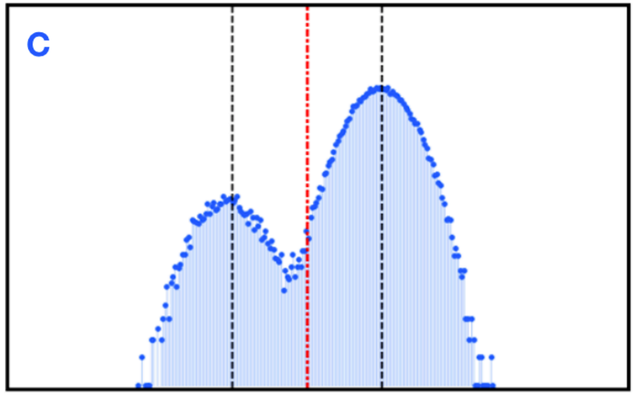
DYNAMICAL DOUBLE EQUILIBRIUM WITH TRANSITION RATE DETERMINED BY PARAMETERS

THE EXTERNAL NOISE z_t INDUCES JUMPS FROM "$c_> \rightarrow c_<$" STATES



$$T_{c_> \rightarrow c_<} \propto e^{-\mathscr{H}/\sigma^2}$$





Take-home messages - Unknown knowns

$$T_{c_> \to c_<} \propto e^{-\mathscr{H}/\sigma^2}$$

Unknown Knowns

Unknown unknowns source of **uncertainties**

$\mathscr{H}$ depends on the parameters of this model

The smallest error (say 10%) on the empirical estimation of any parameters is amplified dramatically by the exponential

(making the predictions fail by an order of magnitude)

Non Linearities introduced by the addition of a simple feedback in the utility function

Dynamics sensitive to Parameters values

THE SIMPLE INTRODUCTION OF A FEEDBACK IN THE BASELINE DSGE LEADS TO INTERESTING EFFECTS !

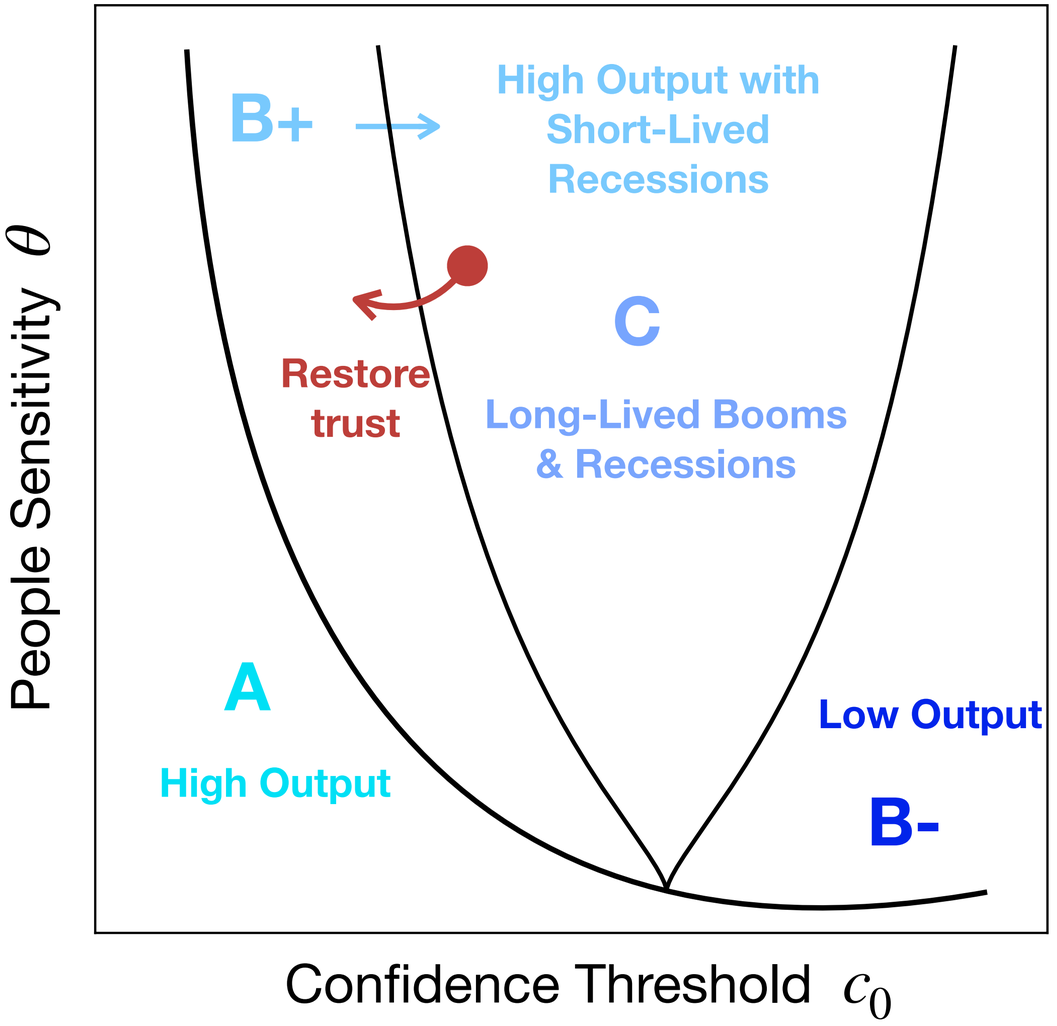
IN A SIMILAR FASHION TO **FORWARD GUIDANCE** WE HAVE SHOWN THAT ONE CONCEPT IS KEY

NARRATIVES AS DRIVERS OF ECONOMIC ACTIVITY [***]

A TOOL FOR POLICY-MAKERS TO

RESTORE TRUST IN A "COLLAPSED ECONOMY"

[***] Narrative Economics
R. Shiller [2017]



What we have achieved so far …

- ☐ **More is different** : overcome the RA framework
  - ☑ **Multi-agents** models
  - ☐ Adding **heterogeneities** and **interactions**
- ☐ Adding minimum elements : introducing **animal spirits**
  - ☑ **Confidence** as a driver of the decision-making process
  - ☐ Notion of "**risk aversion**" when investing
- ☑ **Phase transitions** : recessions as multiple equilibria
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  - ☑ **Consumption driven** collapses
  - ☐ **Supply driven** recessions

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SOME INSIGHTS OF ECONOMIC THEORY

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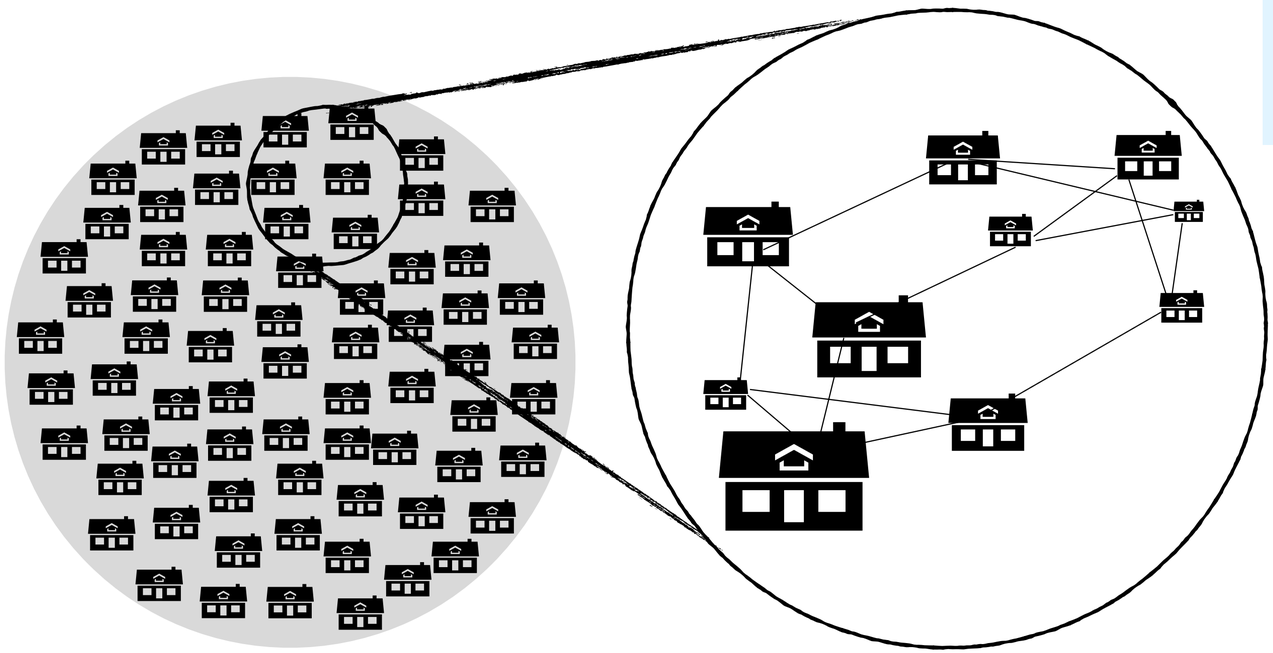
FEEDBACK UTILITY FUNCTION

HOUSEHOLDS ARE THE NODES OF A SOCIAL NETWORK J_{ij} . THEY ESTIMATE THE ECONOMY BY OBSERVING

THE AVERAGE PAST CONSUMPTION OF THEIR NEIGHBORS $\mathcal{N}$



$$U_t^i = f_t^i \cdot \log c_t^i - \gamma \left(n_t^i\right)^2 \ , \qquad f_t^i \to F\left(\sum_{j \in \mathcal{N}(i), j \neq i} J_{ij} \cdot c_{t-1}^j \right)$$

HETEROGENEITIES

INDIVIDUAL PREFERENCES, I.E. $f_t^i = F_t$

SPARSE NETWORK & HETEROGENEITIES

FINITE NUMBER OF HOUSEHOLDS

WHAT CHANGES WITH RESPECT TO THE HOMOGENEOUS CASE ?

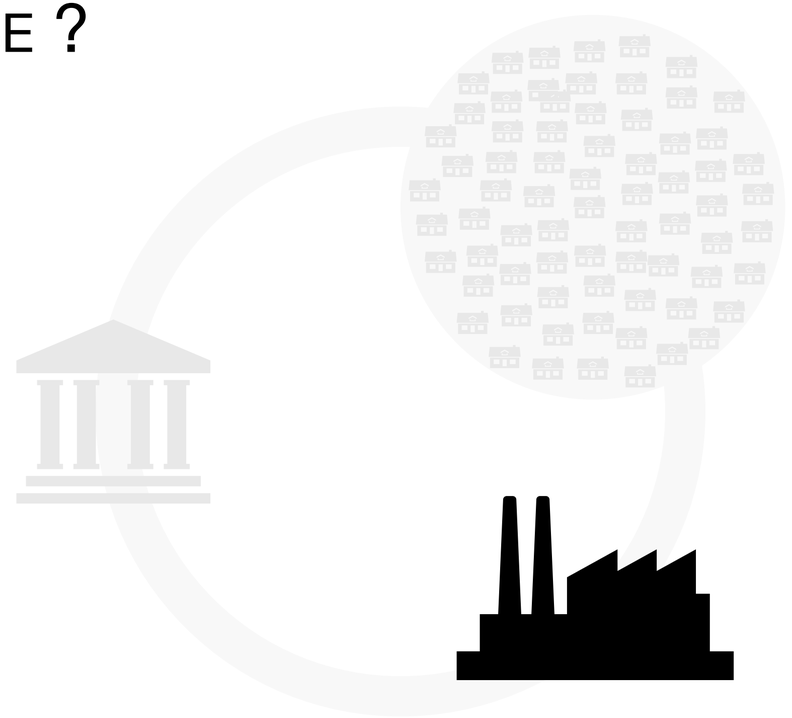
PRODUCTION FUNCTION : $Y_t = \mathfrak{z}_t \frac{N^\alpha}{1-\alpha} \left(\sum_i z^i n_t^i \right)^{1-\alpha}$

OVERALL TECHNOLOGY EXOGENOUS SHOCK

INDIVIDUAL SKILL LEVELS

PROFIT FUNCTION : $\mathbb{P}/p_t = Y_t - \sum_i u_t^i n_t^i$

MARKET CLEARS : $Y_t = \sum_i c_t^i$



INDIVIDUAL WAGES u_t^i DEPEND ON THE INDIVIDUAL SKILL LEVELS

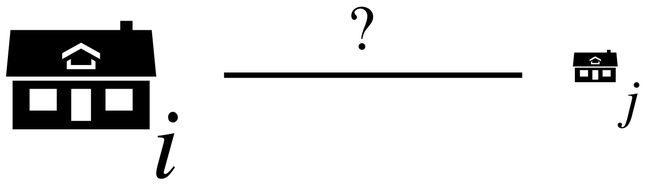
$$u_t^i = \mathfrak{z}_t \, z_t^i \cdot \left(\frac{1}{N} \sum_j z_t^j \cdot n_t^j \right)^{-\alpha}, \forall i$$

WAGES ARE PROPORTIONAL TO INDIVIDUAL SKILLS z_t^i

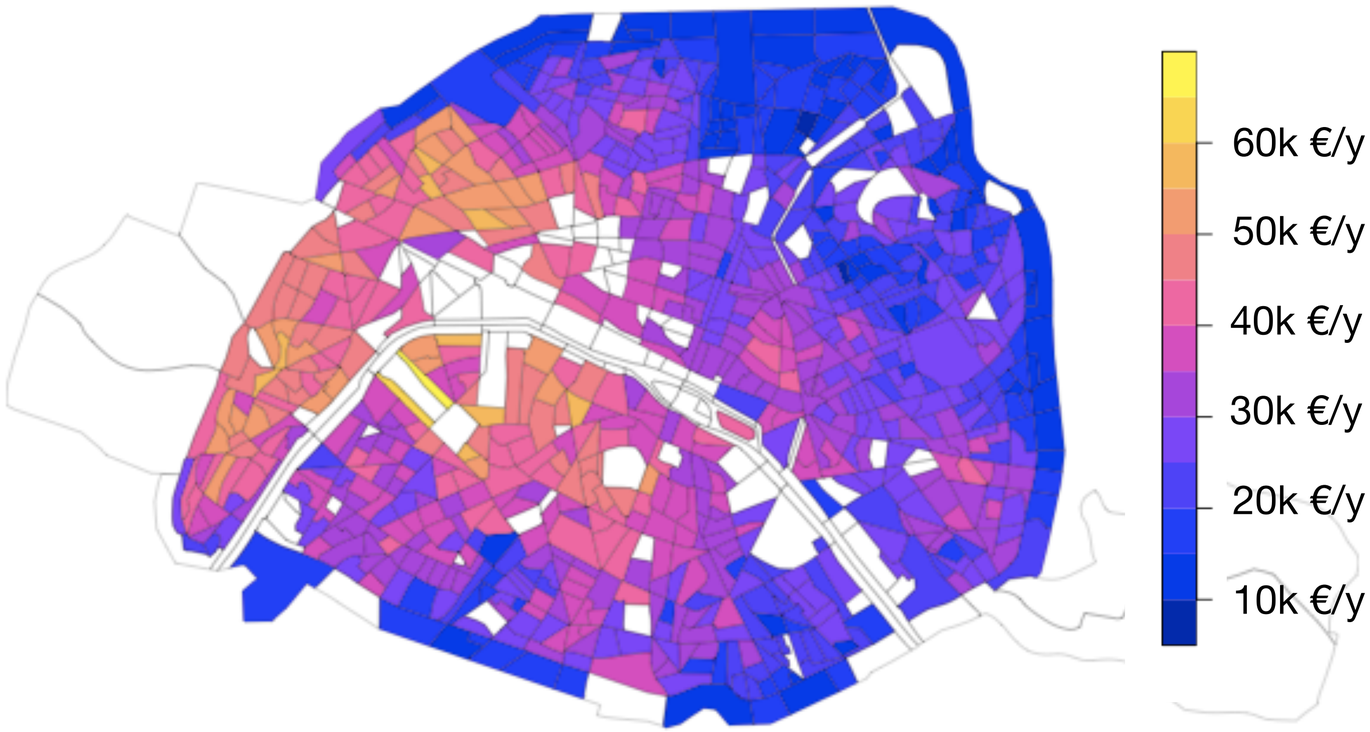
EMPIRICALLY, WAGES ARE EXPONENTIALLY DISTRIBUTED

THE **SOCIAL NETWORK** IS BUILD TO REFLECT **SPATIAL SEGREGATION BY INCOME**[*]

A PARAMETER λ MODULES THE PROBABILITY OF HAVING A BOND BETWEEN AGENTS i AND j



$$p_{ij} \propto \frac{C}{N} \exp\left(-\frac{|z^i - z^j|}{\lambda \, (z^i + z^j)} \right)$$



RANDOM GRAPH ($\lambda \to \infty$)

AGENTS ARE CONNECTED AT RANDOM

SEGREGATED NETWORK ($\lambda \to 0$)

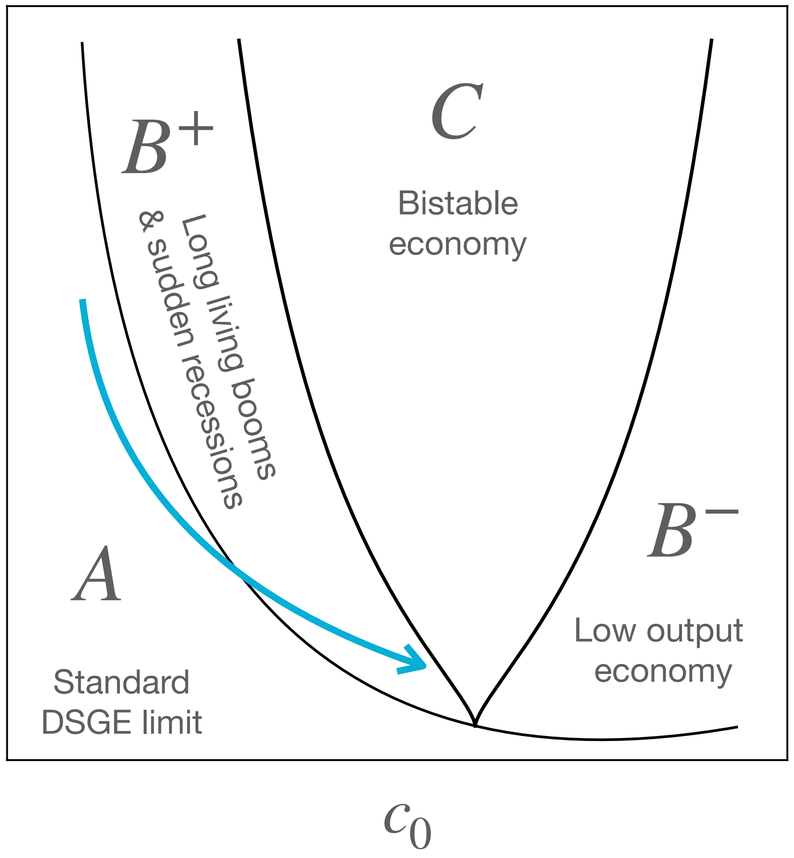
SPATIAL CORRELATION BY INCOME

[*] The Rise of Residential Segregation by Income
P. Taylor and R. A. Fry [2012]

DURING THE EARLY STAGES OF THE 2008 GFC

THE **WEALTHIER END OF THE POPULATION WAS THE MOST PESSIMISTIC**

ABOUT THE STATE OF THE ECONOMY



INDIVIDUAL CONFIDENCE AND **SENSITIVITIES** ARE DEFINED AS :

$$c_0^i = c_0 \cdot (z^i)^{\beta_1} \qquad \theta^i = \theta \cdot (z^i)^{-\beta_2}$$

THE SET OF AGENTS IS REPRESENTED BY A

LINE IN THE PHASE DIAGRAM

SHARING THE CONCAVITY OF THE CRITICAL LINES

β_1 MODULATES THE DEPENDENCE OF c_0^i ON THE SKILLS z^i

β_2 MODULATES THE DEPENDENCE OF θ^i ON THE SKILLS z^i

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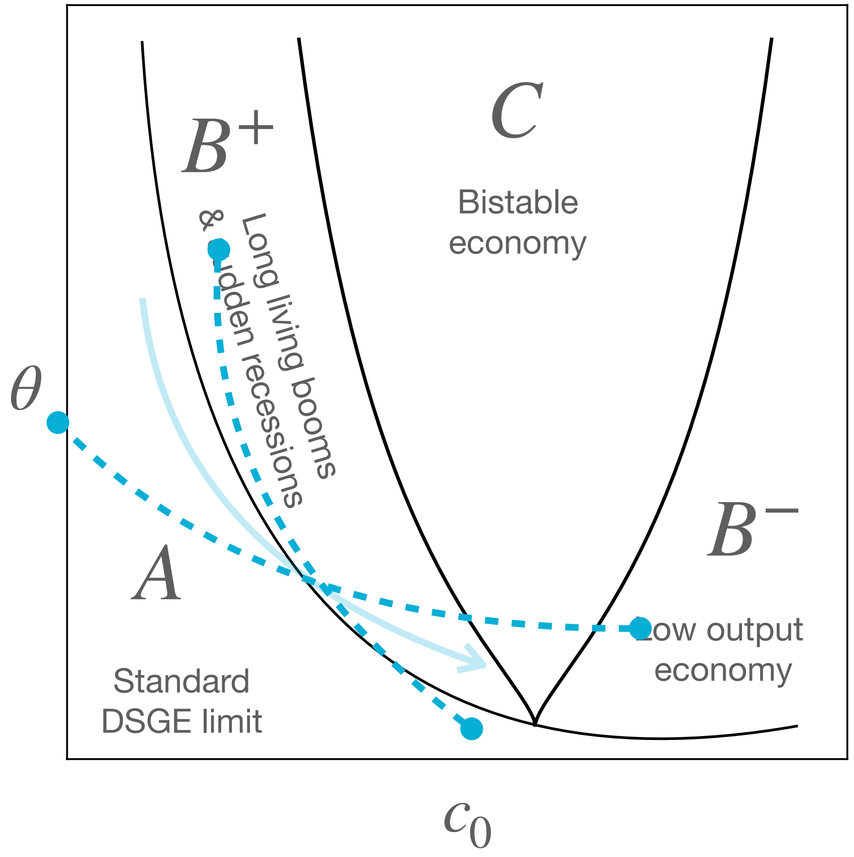

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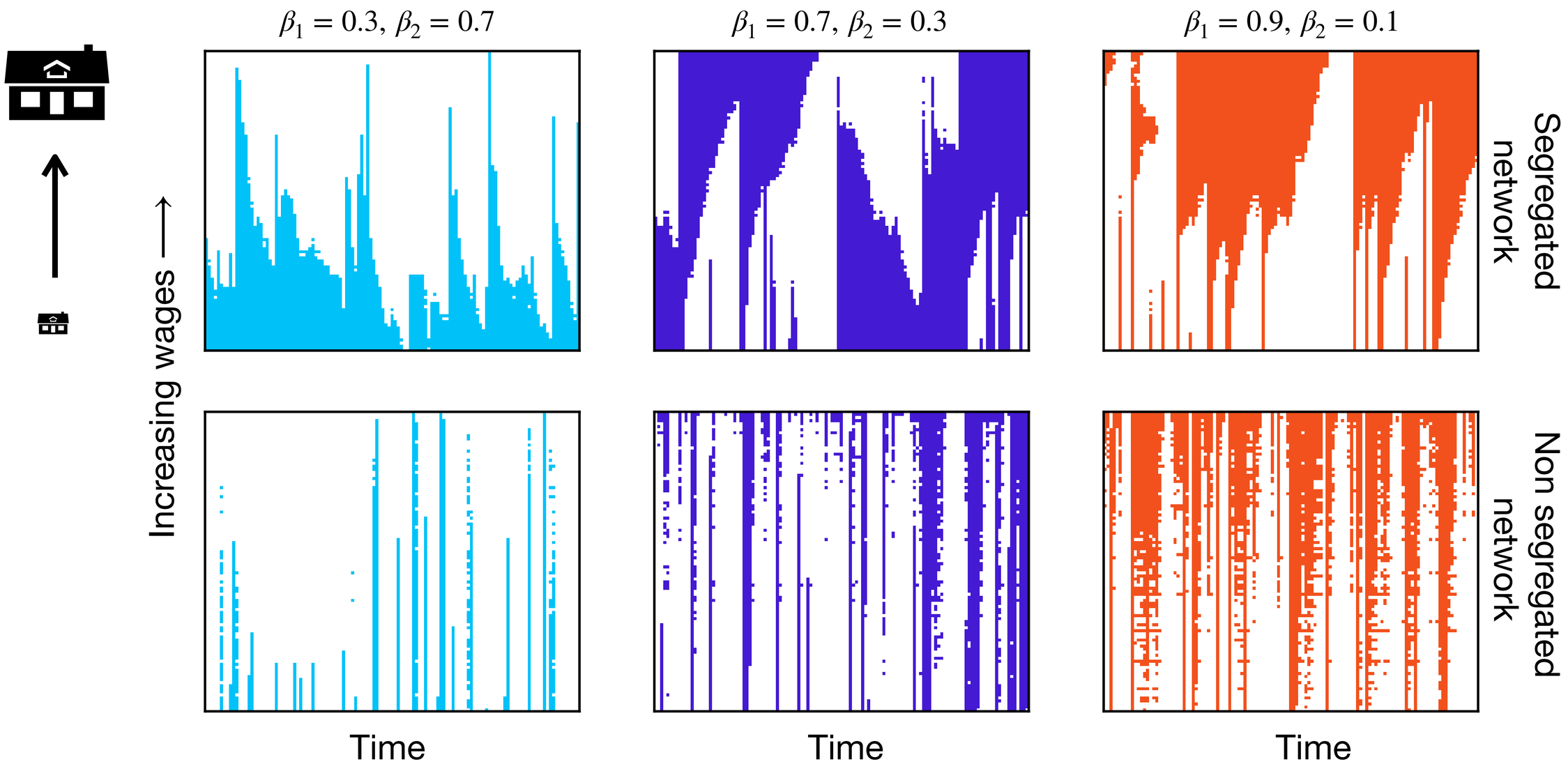
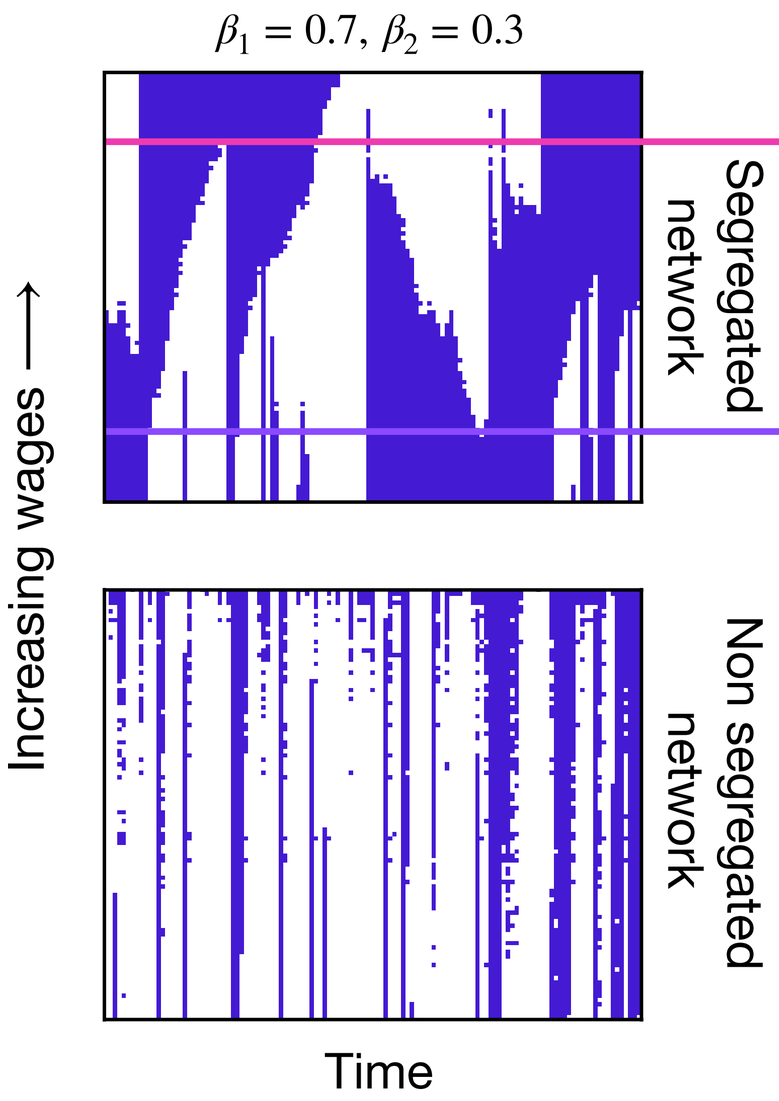
THE CRISES DYNAMICS



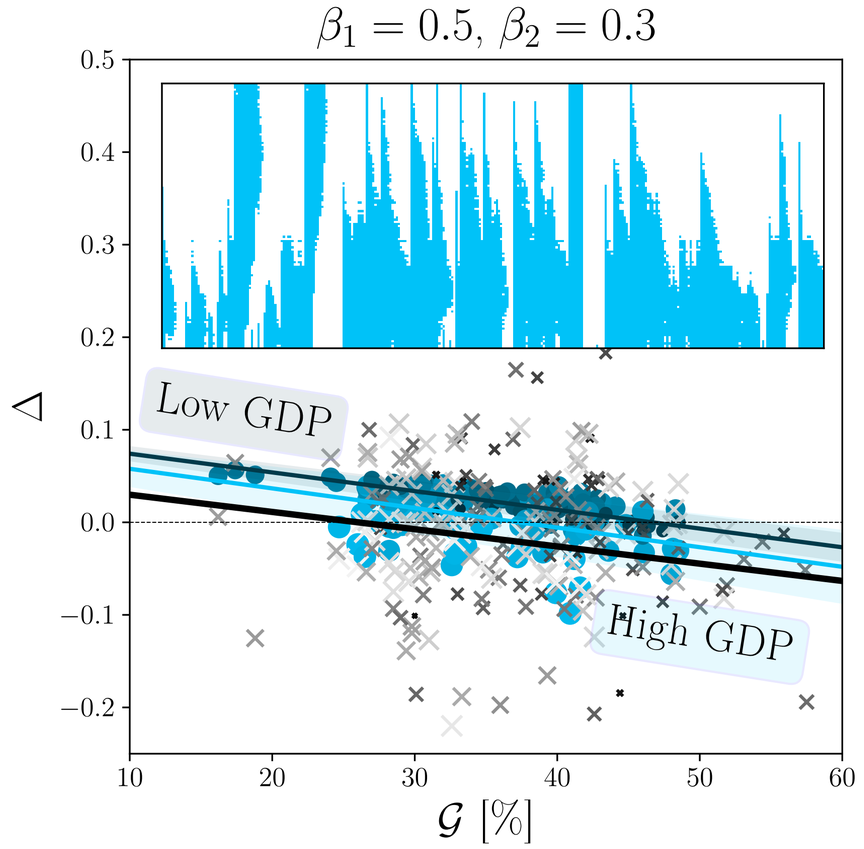
Calibration with real world data



Highest Decile : δc_{10}

Lowest Decile : δc_{90}

$$\Delta = \delta c_{90} - \delta c_{10}$$



Negative correlation vs. Gini index

In unequal countries consumption of wealthiest drops the most

Segregated Network fits the best

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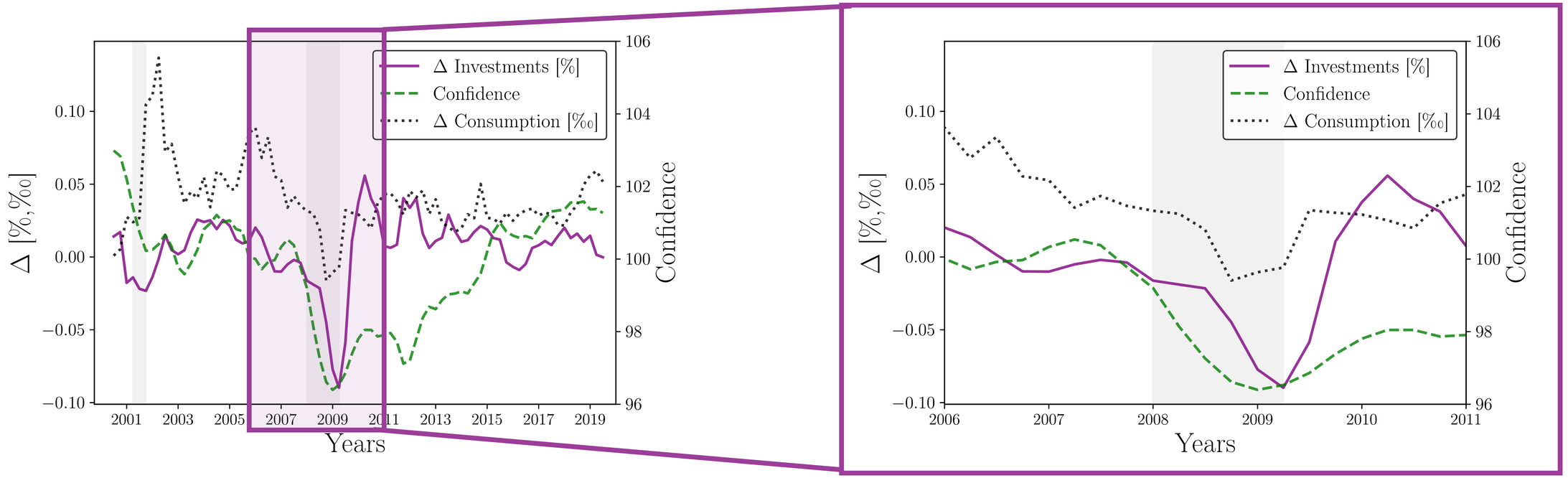
DURING THE 2008 GFC THE **FALL IN CONFIDENCE** LED TO **DRASTIC DROP IN INVESTMENTS**

HOW TO ACCOUNT FOR SIMILAR DYNAMICS ?

INTRODUCE A **CAPITAL MARKET**

PERFECT SUBSTITUTABILITY OF **CAPITAL LEVEL** AND **LABOUR**

INVESTMENTS ALLOCATION PREFERENCES (RISKLESS VS. RISKY)



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LET'S FOCUS ON THE SALIENT POINTS !

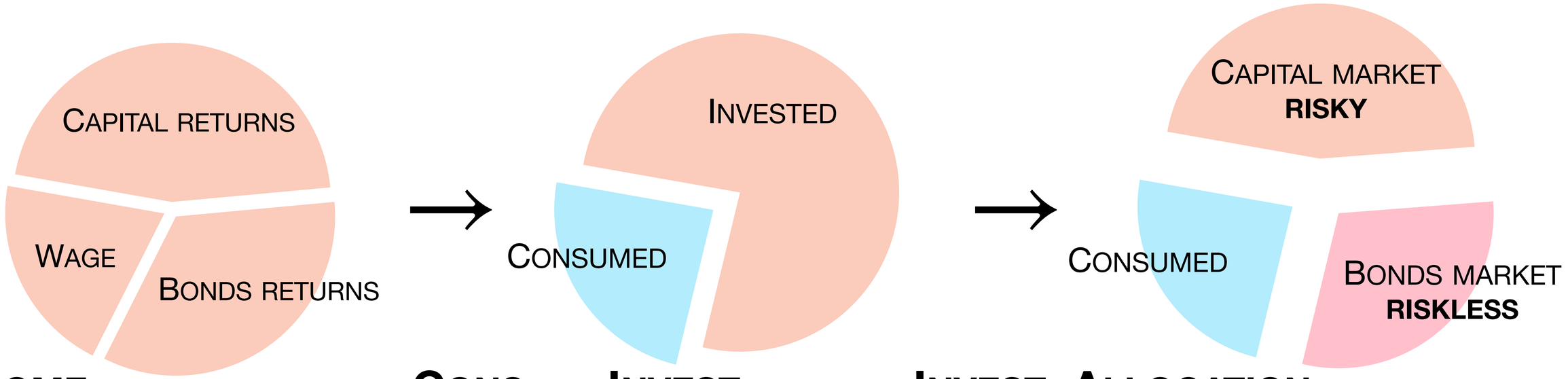
The representative household

The **utility function** reads $U_t = \log c_t - \gamma n_t^2$, as in the reference model

Income is either **Consumed** or **Invested**

Investments are allocated either in

the **Capital Market** (risky) or in the **Bonds Market** (riskless)



Income **Cons. vs. Invest.** **Invest. Allocation**

THE FIRM PRODUCES **ACCORDING TO A CES FUNCTION**

CAPITAL AND LABOUR ARE NOT PERFECTLY SUBSTITUTABLE.

$$Y_t^{\rho} = z_t \cdot \left(\alpha \cdot K_t^{-\rho} + (1-\alpha) \cdot N_t^{-\rho}\right)^{-1/\rho}$$

COBB-DOUGLAS ($\rho \to 0^+$) PRODUCTION FUNCTION

PERFECT ELASTICITY, THE FIRM CAN HIRE LABOUR TO COMPENSATE FOR THE LACK OF CAPITAL

LEONTIEF ($\rho \to \infty$) PRODUCTION FUNCTION

COMPLETE INELASTICITY, CAPITAL AND LABOUR ARE NOT SUBSTITUTABLE

$$Y_t^0 = z_t \cdot N_t^{\alpha} \cdot K_t^{1-\alpha}$$

$$Y_t^{\infty} = z_t \cdot \min\left(K_t, N_t\right)$$

CAPITAL **DEPRECIATES** AT A RATE : $K_t = (1-\delta) \cdot K_{t-1} +$ HOUSEHOLD'S INVESTMENTS

THE FIRM MAXIMIZES ITS **REAL PROFIT FUNCTION** $\mathbb{P}_t^i / p_t$ WRT

LABOUR TO SET **REAL WAGES**
THE CAPITAL LEVEL TO SET IDEAL **OPTIMAL RETURNS**
OPTIMAL RETURNS ARE MODULATED BY AN EXOGENOUS TERM **REAL RETURNS** (E.G. BANKRUPTCIES)

RISKY ALLOCATION

THE CENTRAL BANK PROVIDES **INTEREST RATES**

INTEREST RATES ARE FIXED AND NOT SUBJECT TO SHOCKS

RISK-FREE ALLOCATION

The pseudo financial market

The firm maximizes its **Real Profit Function** $\mathbb{P}_t^i / p_t$

Labour to set **Real Wages**
To the Capital Level to set ideal **Optimal Returns**
Optimal returns are modulated by an exogenous term **Real Returns** (e.g. bankruptcies)
Risky allocation

The central bank provides **Interest Rates**

Interest Rates are fixed and not subject to shocks
Risk-Free allocation

THE HOUSEHOLD OBSERVES THE **INTEREST RATE** r_t AND THE **REAL RETURNS** q_t

THE TREND OF THE **REAL RETURNS** : $\mu_t = \lambda \cdot \mu_{t-1} + (1-\lambda) \cdot q_t$

THEIR **VOLATILITY** : $\sigma_t^2 = \lambda \cdot \sigma_{t-1}^2 + (1-\lambda) \cdot (q_t - \mu_t)^2$

COMPUTES THE **SHARPE RATIO**

$$\mathcal{S}_t := \mathcal{N} \cdot \frac{\mu_t - r_t - \delta}{\sigma_t}$$

$$\mathcal{C}_t := \tanh(\theta \cdot (c_{t-1} - c_0))$$

DECIDES WHERE TO ALLOCATE BY COMPROMISING THE **SHARPE RATIO** AND ITS **CONFIDENCE**

MARKET VS. CONFIDENCE TRENDS

THE HOUSEHOLD OBSERVES THE **INTEREST RATE** r_t AND THE **REAL RETURNS** q_t

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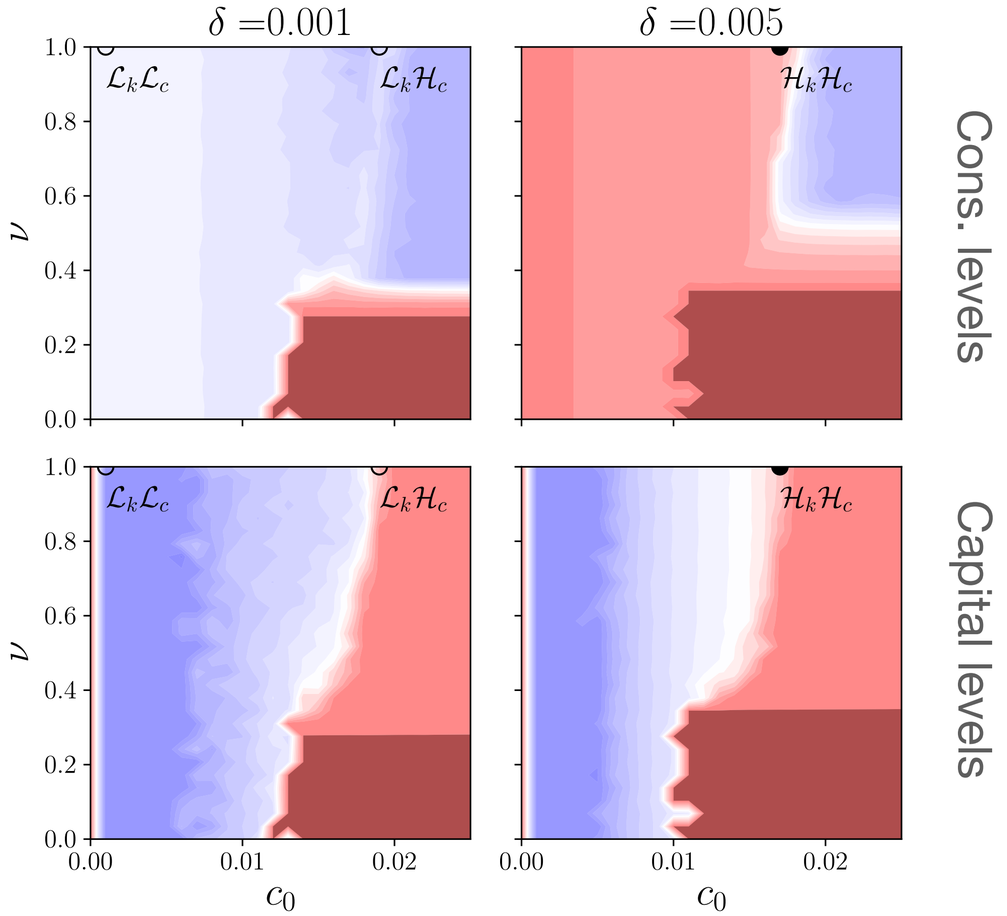
$$\Sigma_t = \nu \cdot \mathcal{S}_t + (1-\nu) \cdot \mathcal{C}_t$$

CONFIDENCE vs. **RATIONALITY**

PHASE DIAGRAM

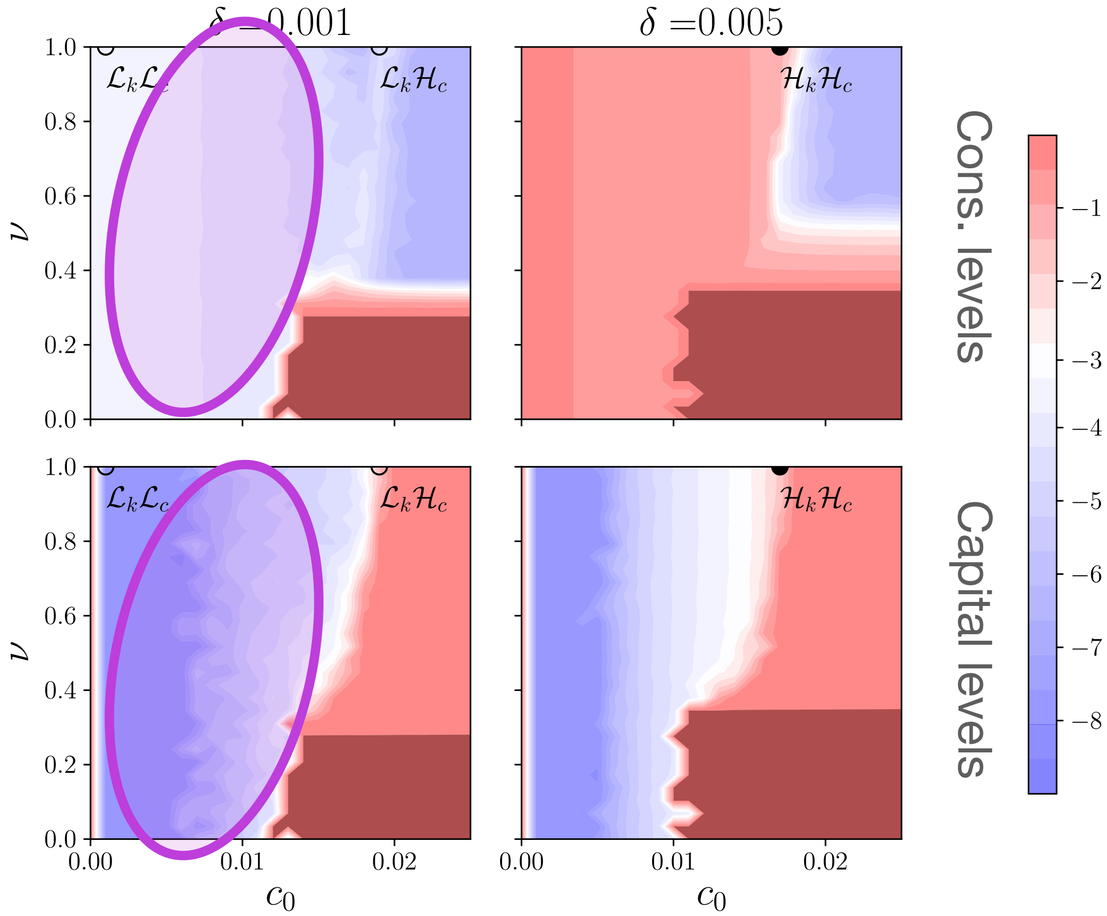


$$\Sigma_t = \nu \cdot \mathcal{S}_t + (1-\nu) \cdot \mathcal{C}_t$$

PROSPEROUS STABILITY

CAPITAL IS ABUNDANT & LOW INTERESTS ON CAPITAL &

RARE CONSUMPTION CRISES **BASELINE DSGE**



$$\Sigma_t = \nu \cdot \mathcal{S}_t + (1-\nu) \cdot \mathcal{C}_t$$

PROSPEROUS STABILITY

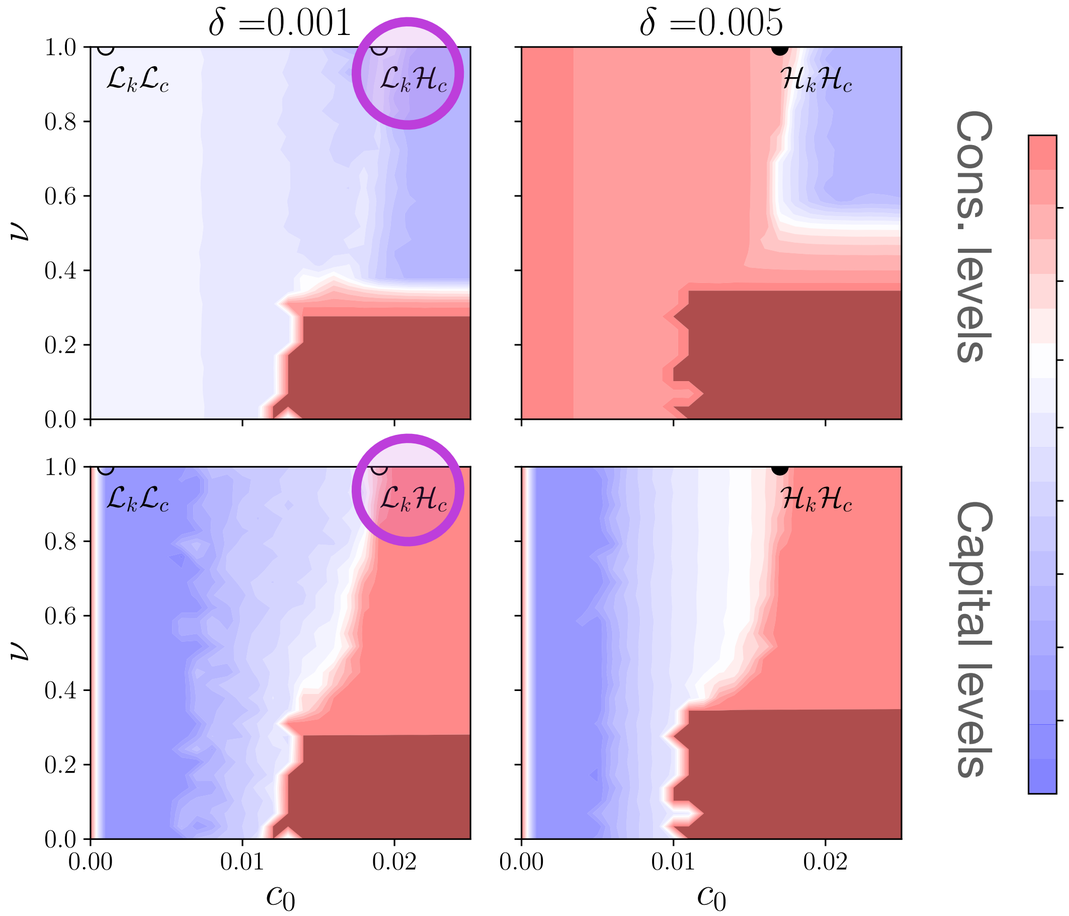
CAPITAL IS ABUNDANT & LOW INTERESTS ON CAPITAL &

RARE CONSUMPTION CRISES **BASELINE DSGE**

PREVALENT CONSUMPTION CRISES

CAPITAL IS ABUNDANT & CONFIDENCE IS LOW &

CONSUMPTION CRISES **MEAN FIELD DSGE**

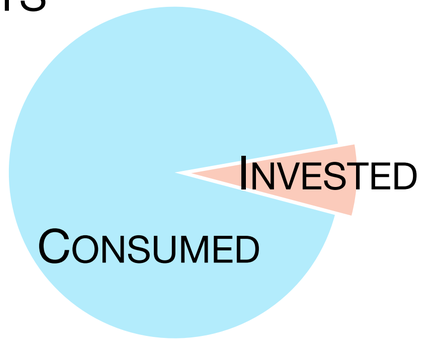


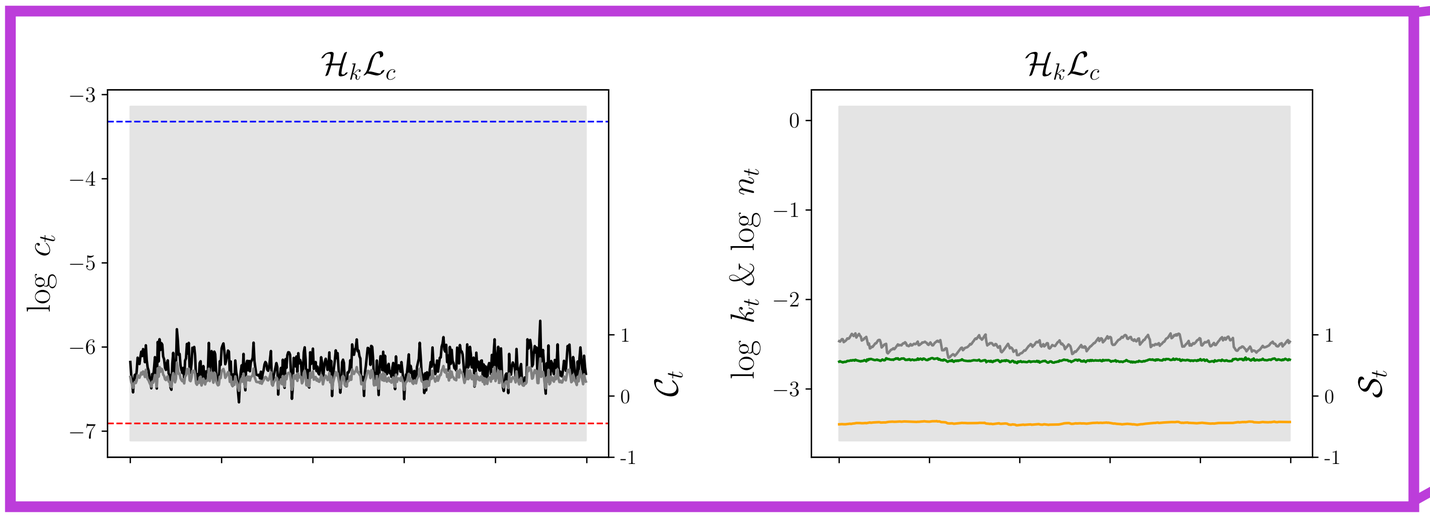
$$\Sigma_t = \nu \cdot \mathcal{S}_t + (1-\nu) \cdot \mathcal{C}_t$$

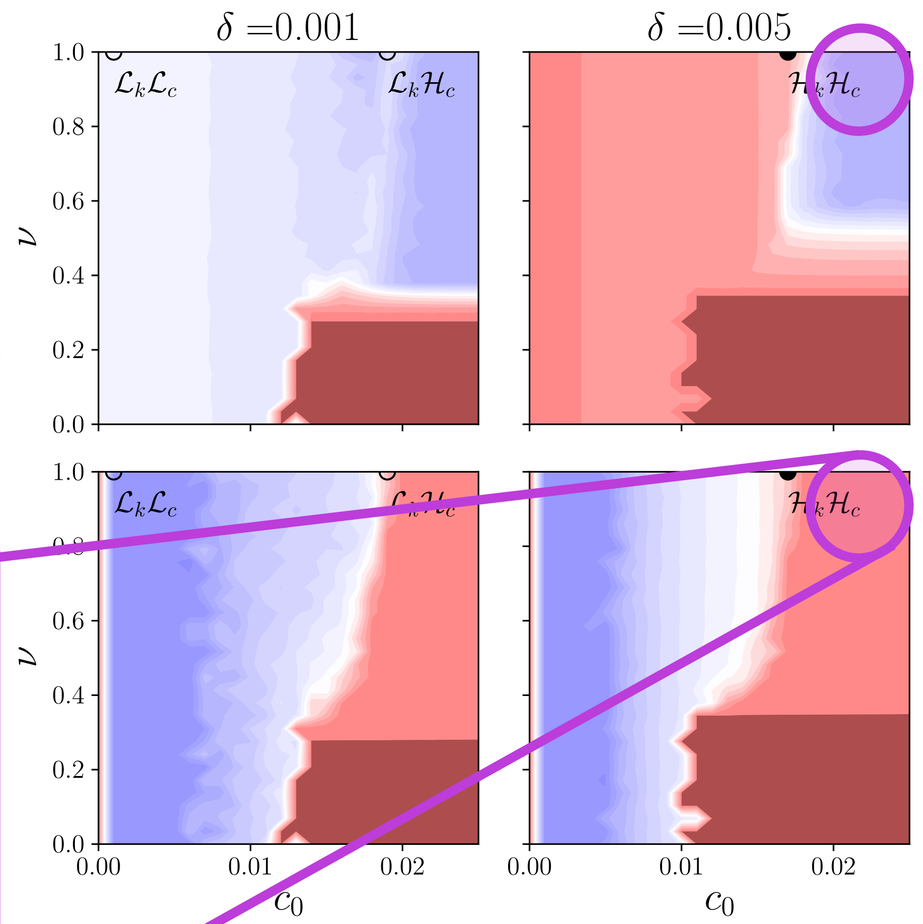
PREVALENT CAPITAL SCARCITY

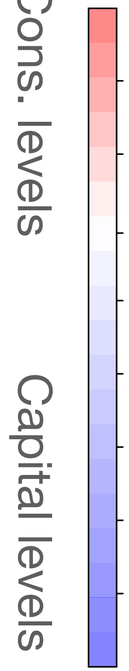
CAPITAL IS SCARCE & HIGH INTERESTS ON CAPITAL &
CONFIDENCE IS HIGH AND LIMIT INVESTMENTS

CURRENTLY RELEVANT REGIME









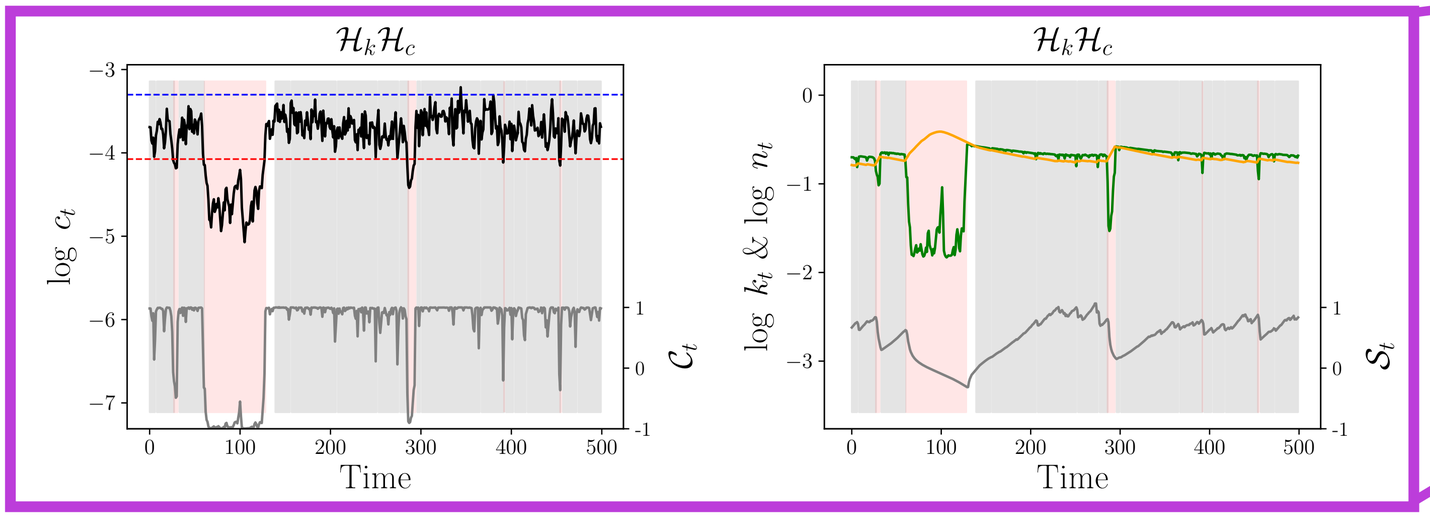
$$\Sigma_t = \nu \cdot \mathcal{S}_t + (1-\nu) \cdot \mathcal{C}_t$$

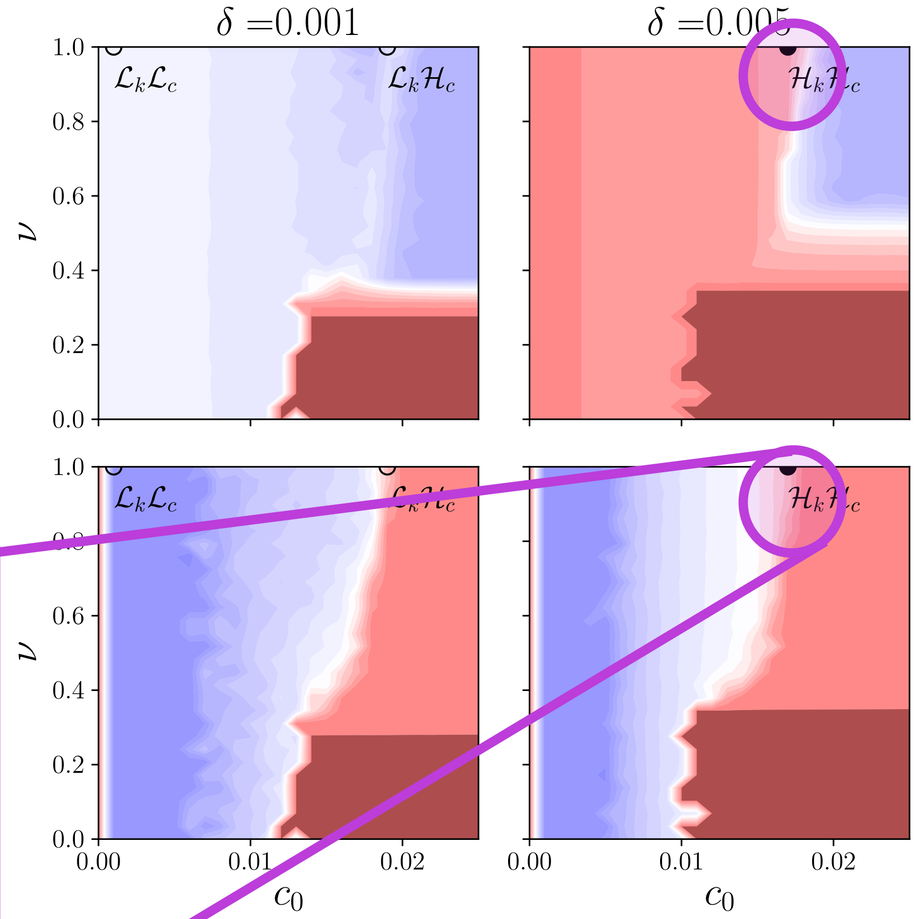
CAPITAL SCARCITY & CONSUMPTION CRISES

CAPITAL IS SCARCE & HIGH INTERESTS ON CAPITAL & CONFIDENCE IS LOW

FAR FROM OPTIMAL STATE

CAPITAL SCARCITY TRIGGERS CONSUMPTION CRISES





$$\Sigma_t = \nu \cdot \mathcal{S}_t + (1-\nu) \cdot \mathcal{C}_t$$

What we have achieved so far …

- ☑ **More is different** : overcome the RA framework
  - ☑ **Multi-agents** models
  - ☑ Adding **heterogeneities** and **interactions**
- ☑ Adding minimum elements : introducing **animal spirits**
  - ☑ **Confidence** as a driver of the decision-making process
  - ☑ Notion of "**risk aversion**" when investing
- ☑ **Phase transitions** : recessions as multiple equilibria
  - ☑ Draw phase diagrams characterizing the parameter space
- ☑ **Non-linearities** : endogenously amplified shocks
  - ☑ **Consumption driven** collapses
  - ☑ **Supply driven** recessions

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Conclusions

- ✓ **More is different** : overcome the RA framework
- ✓ Adding minimum elements : introducing **animal spirits**
- ✓ **Phase transitions** : recessions as multiple-equilibria
- ✓ **Non-linearities** : endogenously amplified shocks

More to Be Done

Adding missing ingredients …

Add **Banking / Financial**[*] system
Firms' **Heterogeneities / Network**[**]
Question **Market Clearing**
Incoordination of **Supply** and **Demand**

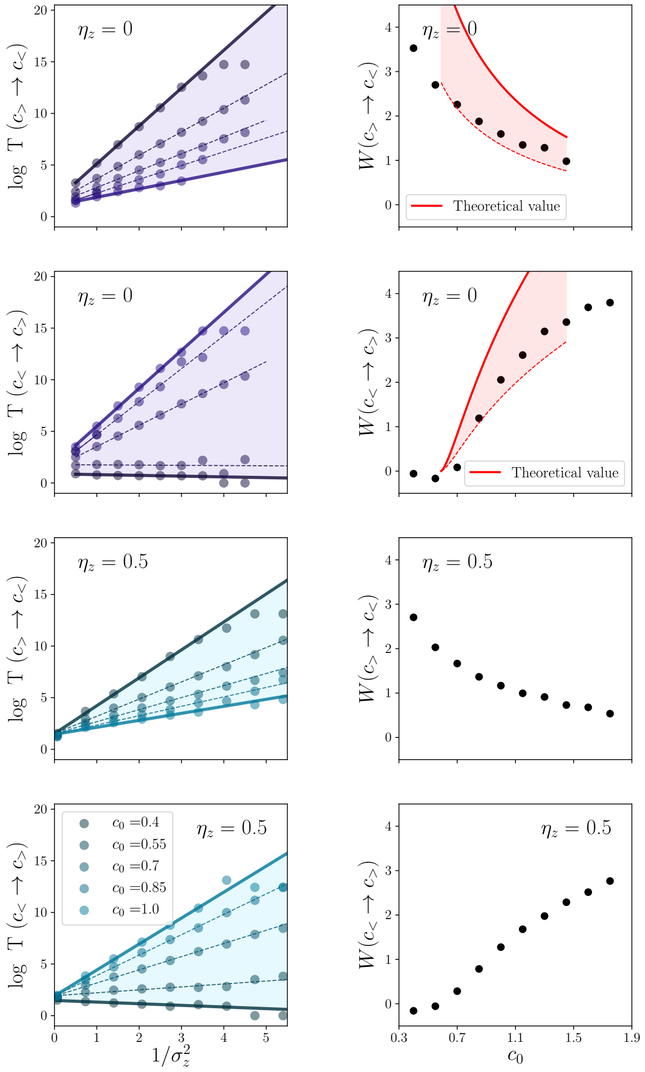
What should be the goal of Macroeconomic models ?

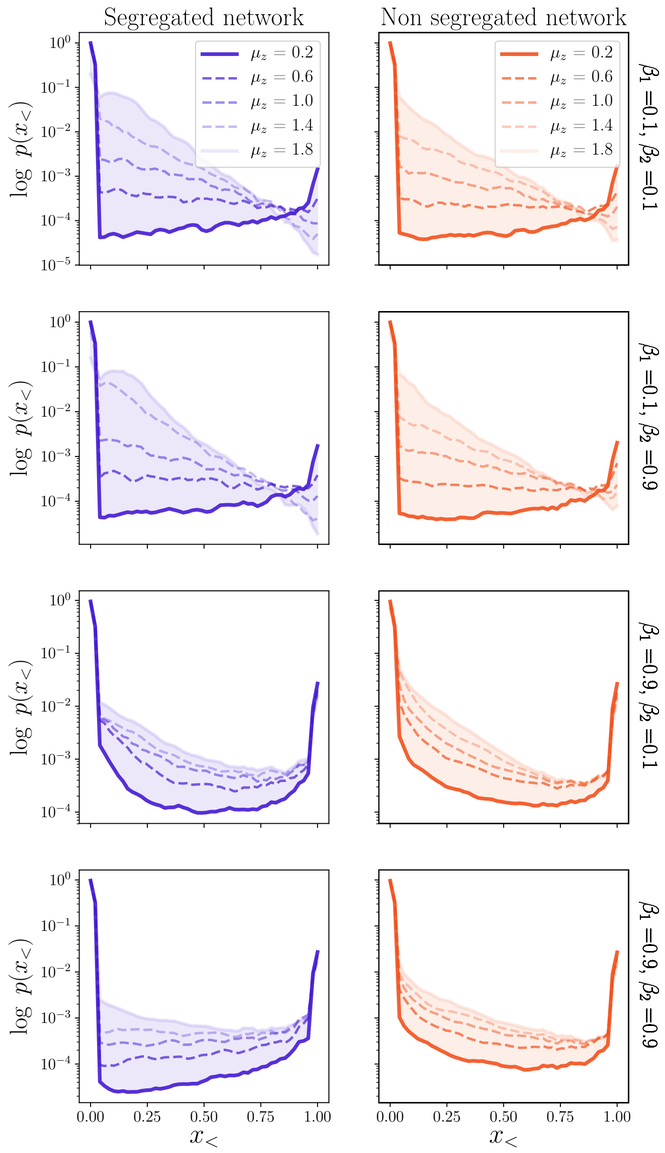
Weather Forecasting versus **Climatology**
Generators of possible scenarios

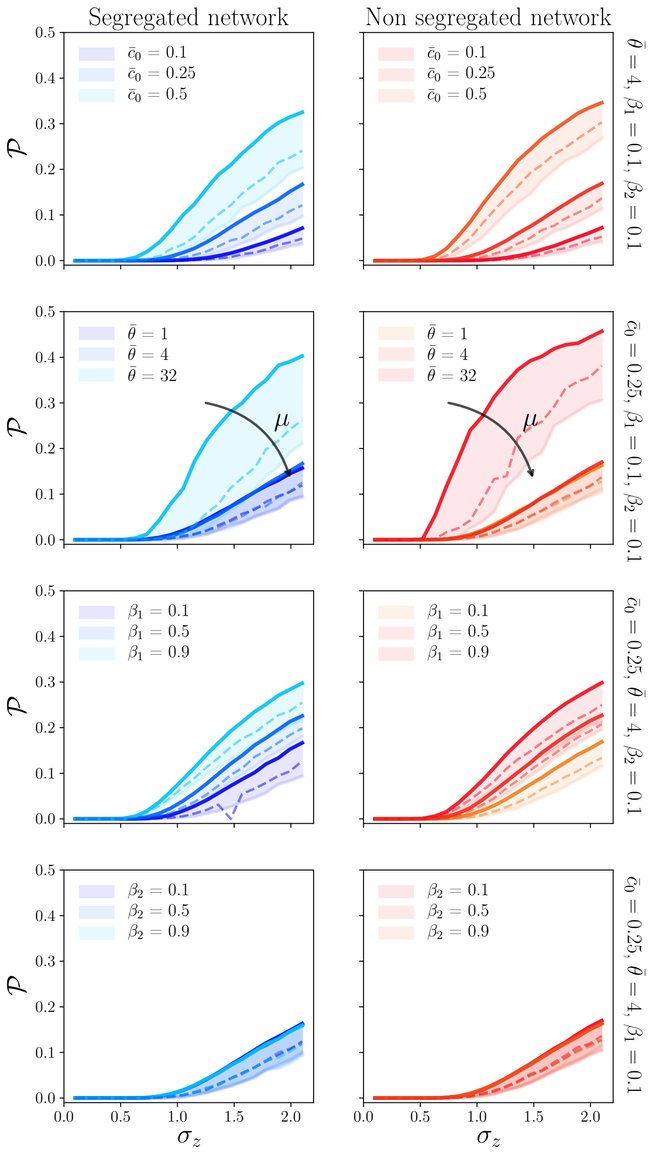
[*] Booms and banking crises
F. Boissay et al. [2016]

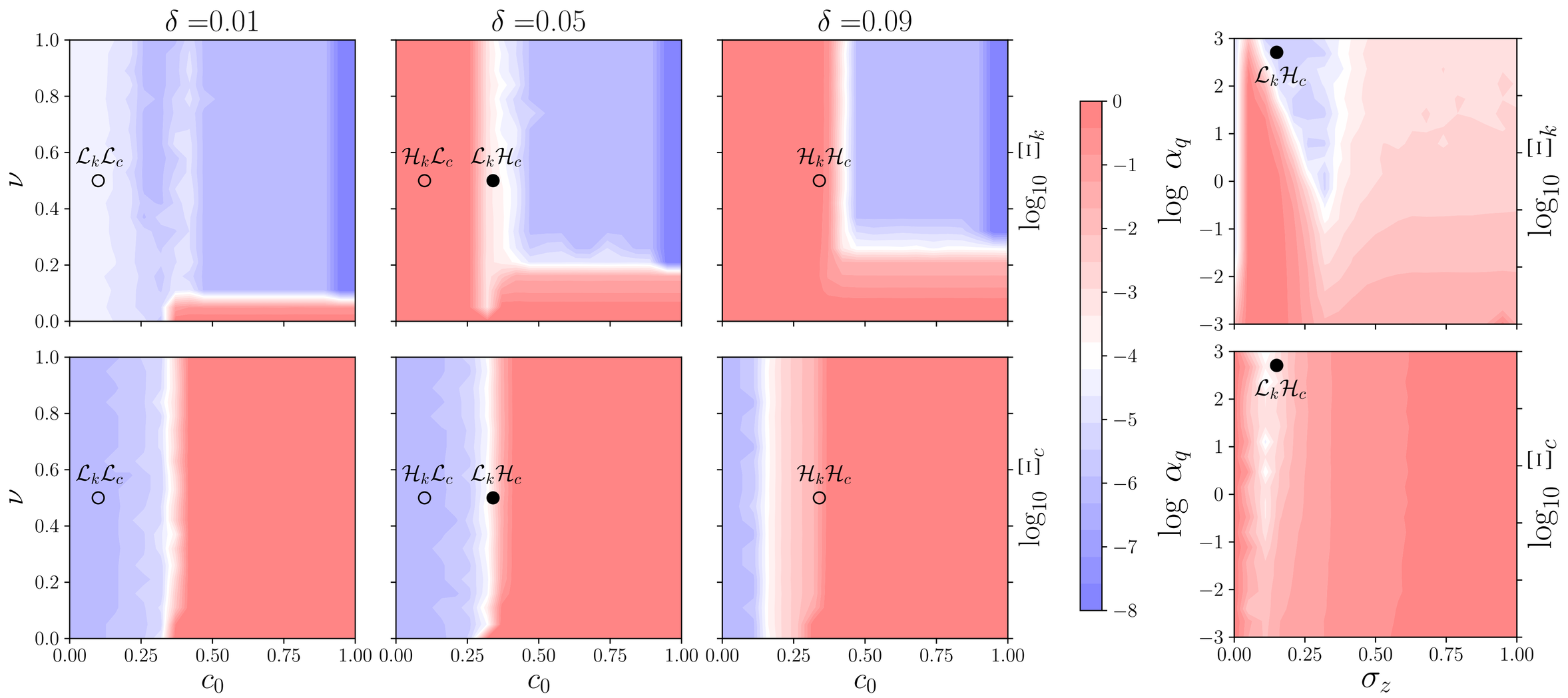
[**] Tâtonnement, Approach to Equilibrium and Excess Volatility in Firm Networks
T. Dessertaine et al [2020]

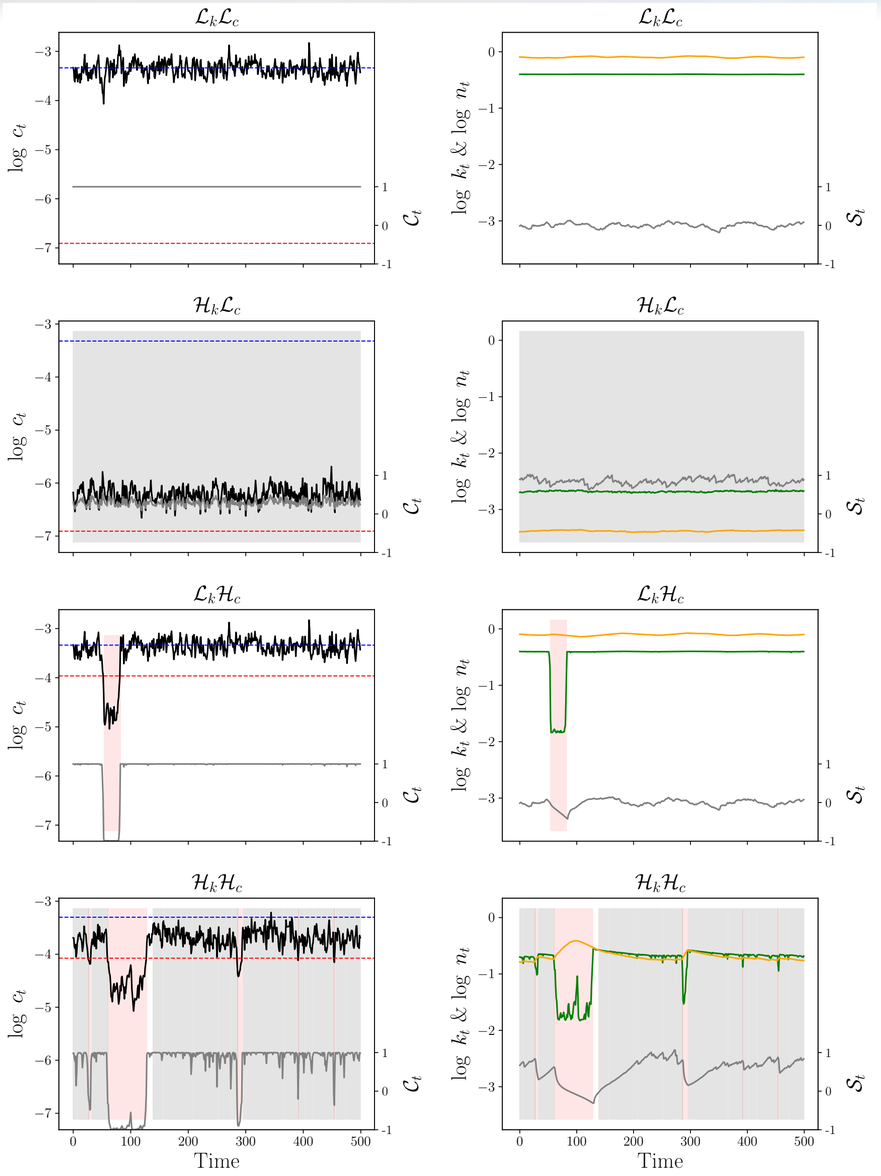
THANK YOU

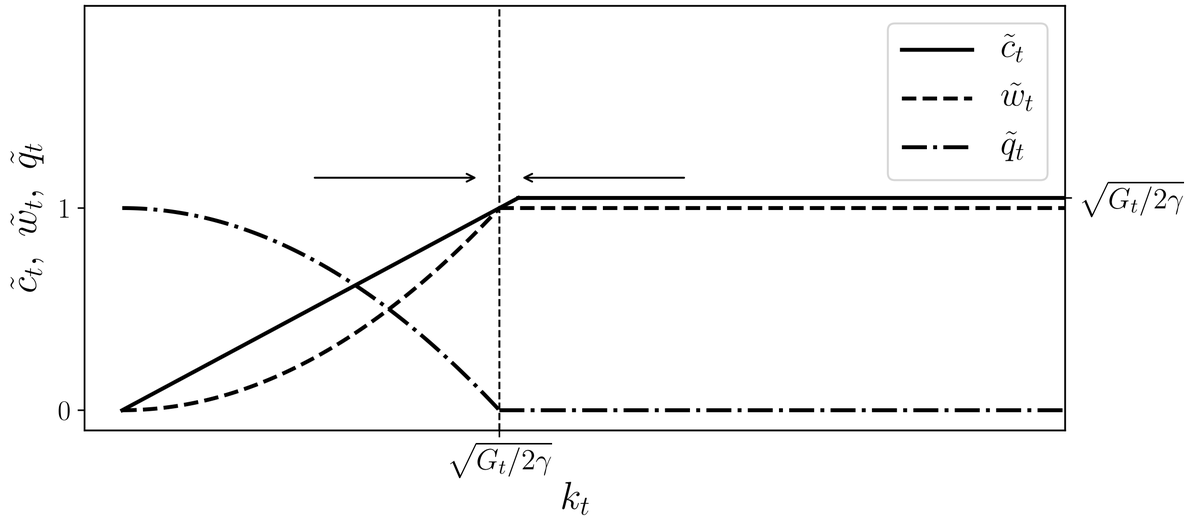

$\eta_z = 0$
log T $(c_> \to c_<)$
$W(c_> \to c_<)$
Theoretical value
$\eta_z = 0$
log T $(c_< \to c_>)$
$W(c_< \to c_>)$
Theoretical value
$\eta_z = 0.5$
log T $(c_> \to c_<)$
$W(c_> \to c_<)$
c_0 =0.4
c_0 =0.55
c_0 =0.7
c_0 =0.85
c_0 =1.0
$\eta_z = 0.5$
log T $(c_< \to c_>)$
$1/\sigma_z^2$
$\eta_z = 0.5$
$W(c_< \to c_>)$
c_0

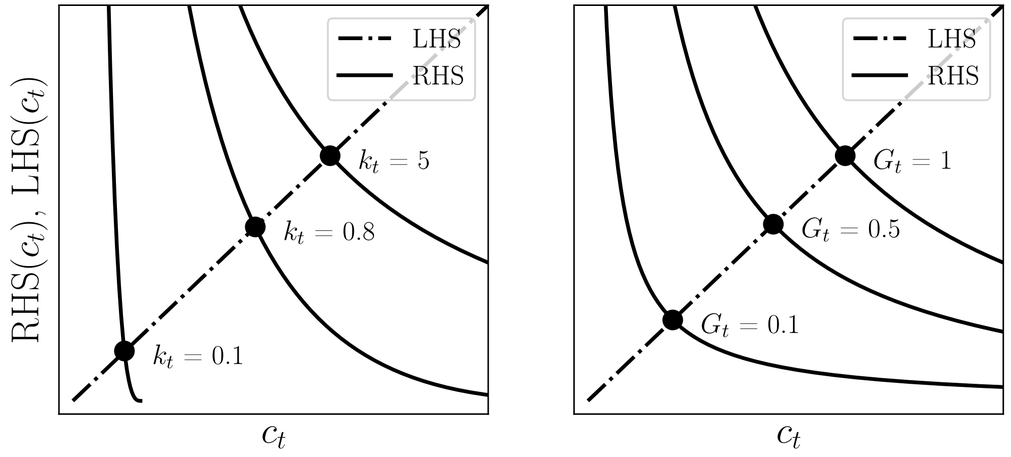

Segregated network
Non segregated network
$\log\ p(x_<)$
$\mu_z = 0.2$
$\mu_z = 0.6$
$\mu_z = 1.0$
$\mu_z = 1.4$
$\mu_z = 1.8$
β_1 =0.1, β_2 =0.1
β_1 =0.1, β_2 =0.9
β_1 =0.9, β_2 =0.1
β_1 =0.9, β_2 =0.9
$x_<$

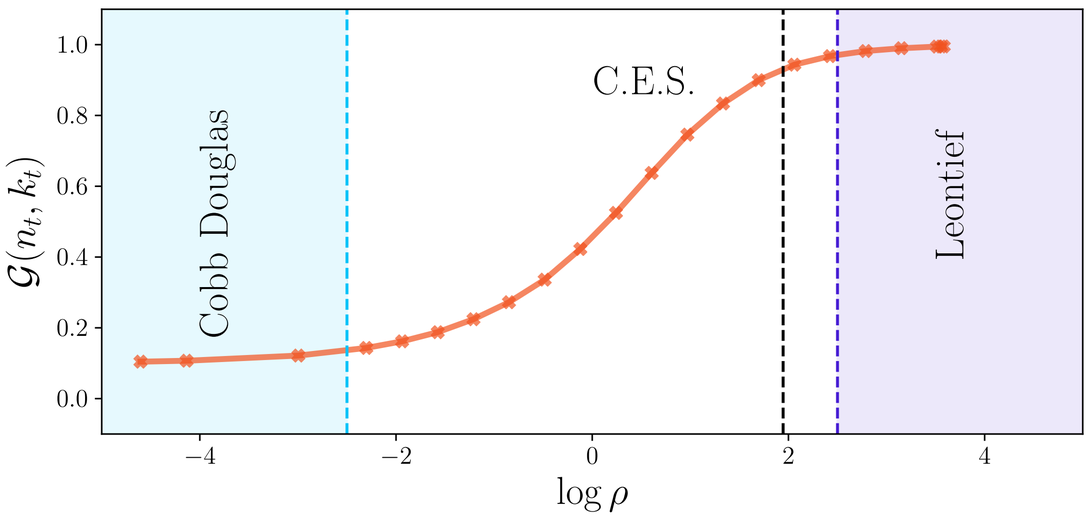

Segregated network
Non segregated network
$\mathcal{P}$
$\bar{c}_0 = 0.1$
$\bar{c}_0 = 0.25$
$\bar{c}_0 = 0.5$
$\bar{\theta} = 1$
$\bar{\theta} = 4$
$\bar{\theta} = 32$
μ
$\beta_1 = 0.1$
$\beta_1 = 0.5$
$\beta_1 = 0.9$
$\beta_2 = 0.1$
$\beta_2 = 0.5$
$\beta_2 = 0.9$
$\bar{\theta} = 4, \beta_1 = 0.1, \beta_2 = 0.1$
$\bar{c}_0 = 0.25, \beta_1 = 0.1, \beta_2 = 0.1$
$\bar{c}_0 = 0.25, \bar{\theta} = 4, \beta_2 = 0.1$
$\bar{c}_0 = 0.25, \bar{\theta} = 4, \beta_1 = 0.1$
σ_z

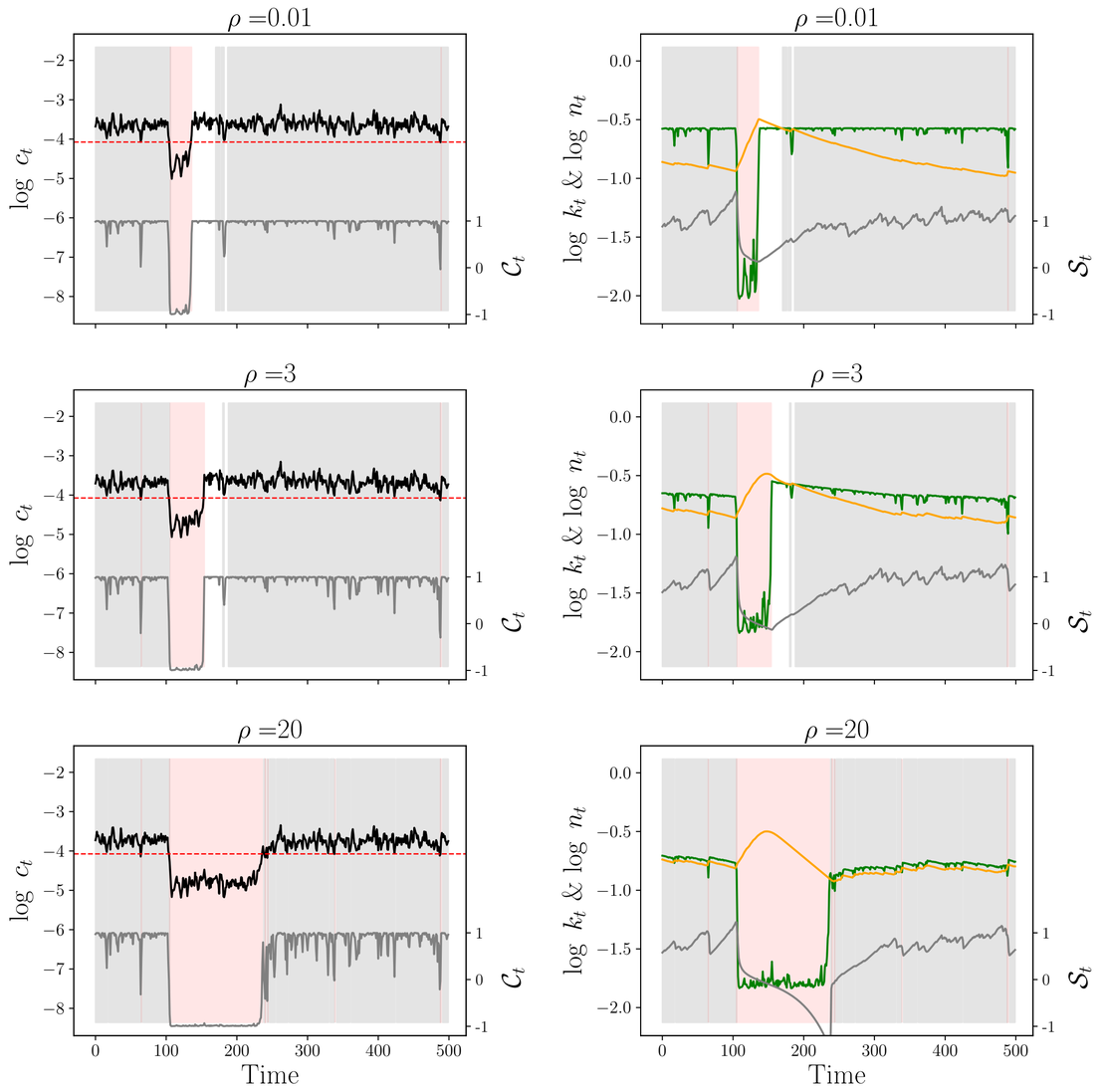

δ =0.01
δ =0.05
δ =0.09
$\mathcal{L}_k\mathcal{L}_c$
$\mathcal{H}_k\mathcal{L}_c$
$\mathcal{L}_k\mathcal{H}_c$
$\mathcal{H}_k\mathcal{H}_c$
ν
c_0
$\log_{10}[\Gamma_k]$
$\log_{10}[\Gamma_c]$
$\log\ \alpha_q$
σ_z

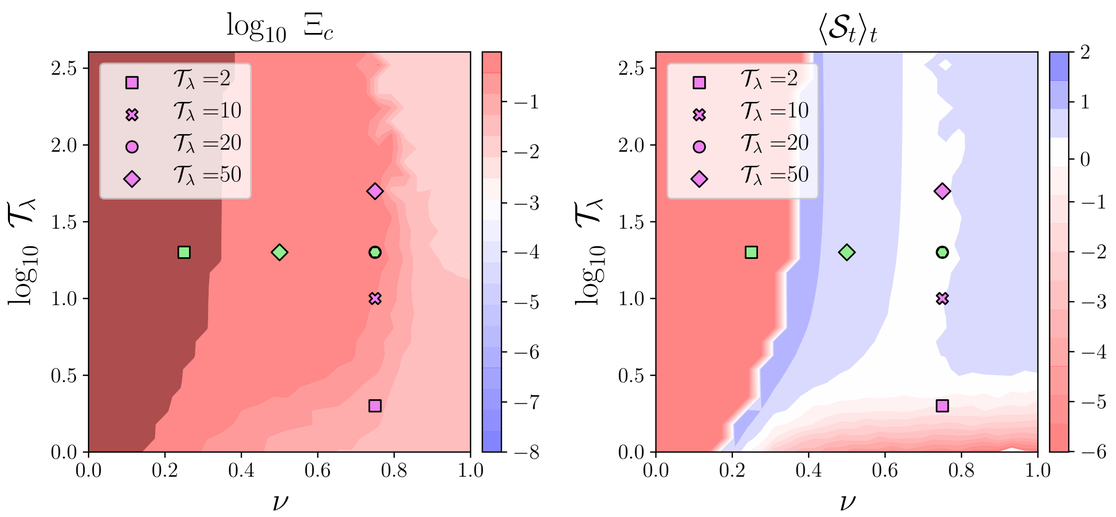

$\mathcal{L}_k\mathcal{L}_c$
$\mathcal{H}_k\mathcal{L}_c$
$\mathcal{L}_k\mathcal{H}_c$
$\mathcal{H}_k\mathcal{H}_c$
log c_t
$\mathcal{C}_t$
log k_t & log n_t
$\mathcal{S}_t$
Time


$\tilde{c}_t$
$\tilde{w}_t$
$\tilde{q}_t$
$\tilde{c}_t,\ \tilde{w}_t,\ \tilde{q}_t$
$\sqrt{G_t/2\gamma}$
k_t

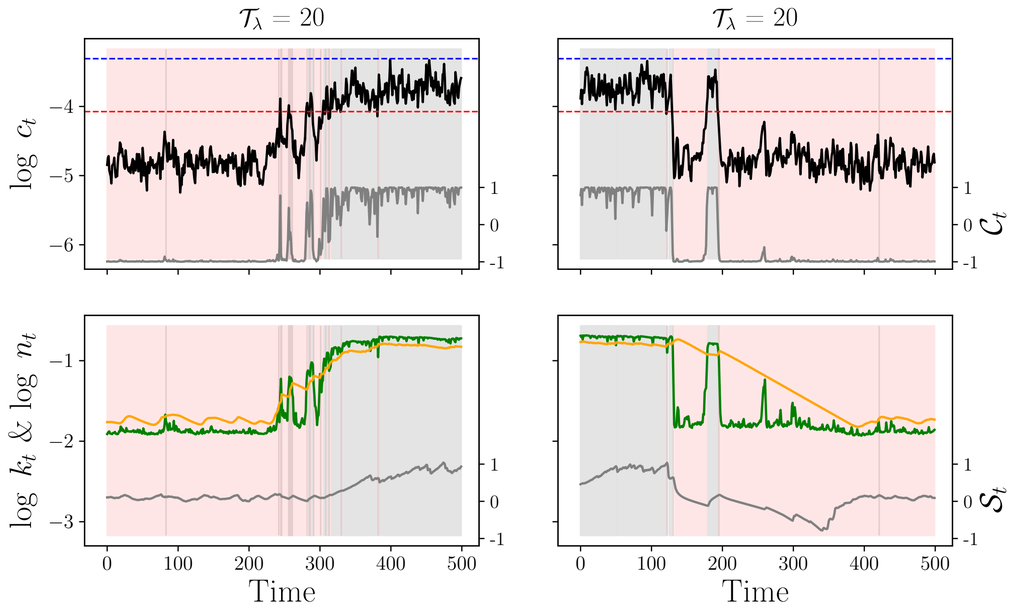

LHS
RHS
$k_t = 5$
$k_t = 0.8$
$k_t = 0.1$
RHS(c_t), LHS(c_t)
c_t
$G_t = 1$
$G_t = 0.5$
$G_t = 0.1$

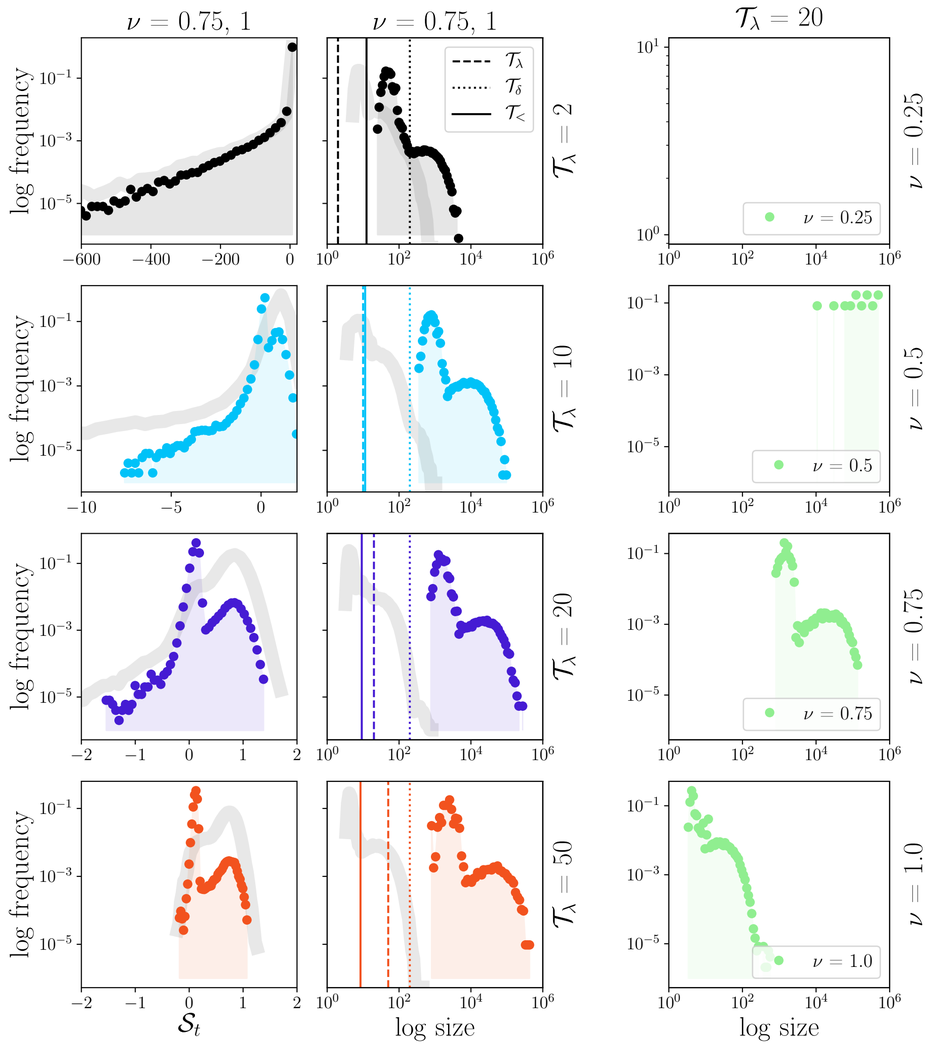

Cobb Douglas
C.E.S.
Leontief
$\mathcal{G}(n_t, k_t)$
$\log \rho$


ρ =0.01
ρ =3
ρ =20
$\log\ c_t$
$\log\ k_t$ & $\log\ n_t$
$\mathcal{C}_t$
$\mathcal{S}_t$
Time


$\log_{10}\ \Xi_c$
$\mathcal{T}_\lambda$ =2
$\mathcal{T}_\lambda$ =10
$\mathcal{T}_\lambda$ =20
$\mathcal{T}_\lambda$ =50
$\log_{10}\ \mathcal{T}_\lambda$
ν

$\langle \mathcal{S}_t \rangle_t$
$\mathcal{T}_\lambda$ =2
$\mathcal{T}_\lambda$ =10
$\mathcal{T}_\lambda$ =20
$\mathcal{T}_\lambda$ =50
$\log_{10}\ \mathcal{T}_\lambda$
ν


$\mathcal{T}_\lambda = 20$
$\mathcal{T}_\lambda = 20$
$\log\ c_t$
$\mathcal{C}_t$
$\log\ k_t$ & $\log\ n_t$
$\mathcal{S}_t$
Time
Time


$\nu = 0.75, 1$
$\nu = 0.75, 1$
$\mathcal{T}_\lambda = 20$
$\mathcal{T}_\lambda$
$\mathcal{T}_\delta$
$\mathcal{T}_<$
log frequency
$\mathcal{T}_\lambda = 2$
$\mathcal{T}_\lambda = 10$
$\mathcal{T}_\lambda = 20$
$\mathcal{T}_\lambda = 50$
$\nu = 0.25$
$\nu = 0.5$
$\nu = 0.75$
$\nu = 1.0$
$\mathcal{S}_t$
log size
log size