Agent-based Macroeconomics: Model Design, Empirical Grounding and Policy Analysis

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Outline of the Workshop

1. Short Motivation and Prelude: Complexity and Economic Modeling
2. Model Design
   i. Approaches for Designing Behavioral Rules
   ii. [Interaction Protocols]

Break (15mins)

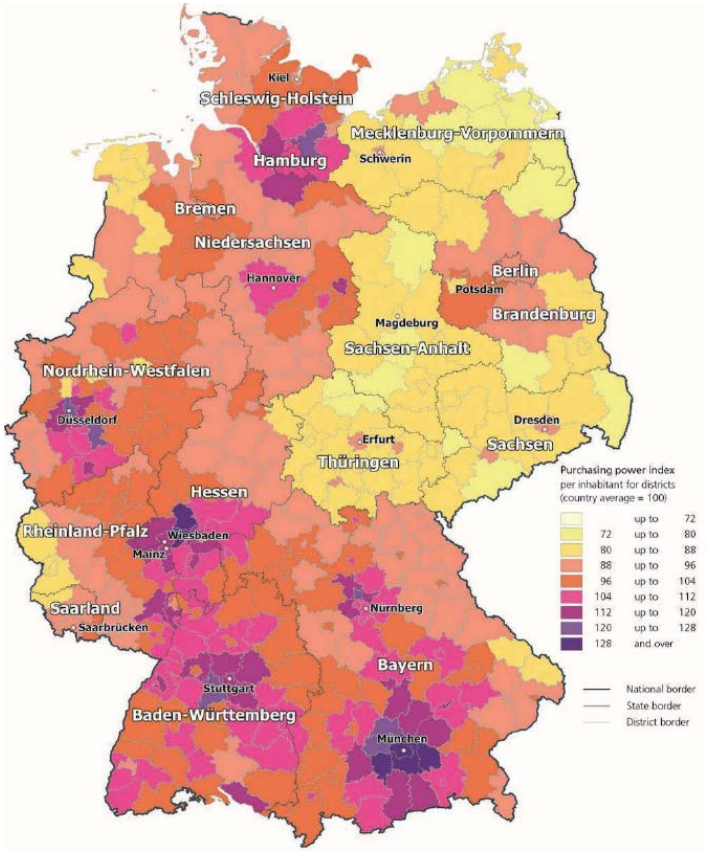
3. Empirical Validation and Calibration
4. Analysis of Simulation Output

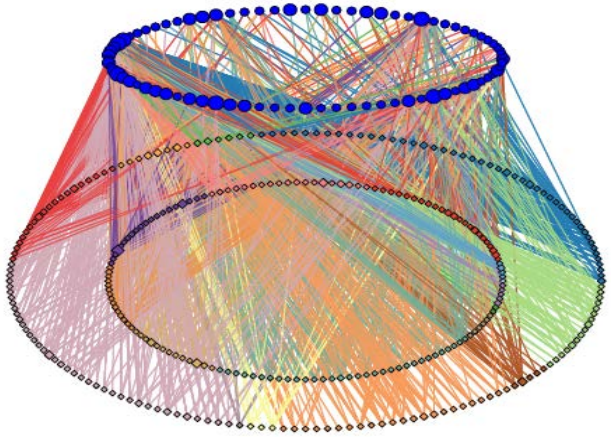
Break (15mins)

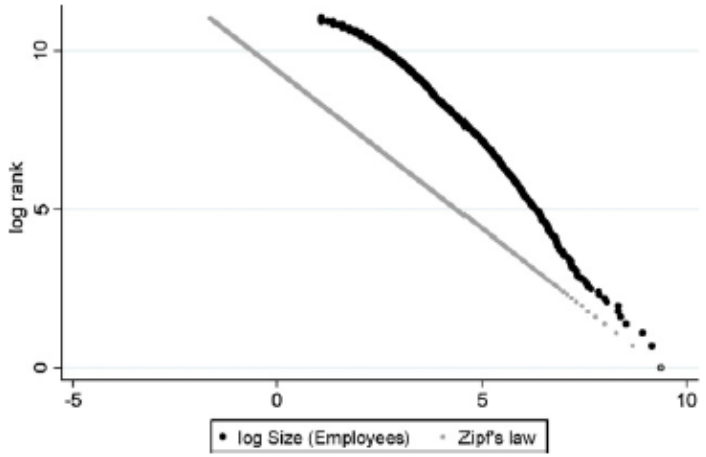
5. Policy Analysis: an illustrative example
6. Fostering Transparency, Reproducibility and Replication: the ETACE Virtual Appliance (VA)
   i. Short Demo
   ii. Exercise Session (for those who want to play with the VA)

1. Complexity and Economic Modeling

- The economy is a very complex system of heterogeneous interacting agents…







Complexity and Economic Modeling

- How much of this complexity should be captured in a model?
  - Which type of agents should be included (firms, households, banks,..)
  - Which properties characterize different type of agents?
  - What kind of rules and protocols govern exchange of goods and information?
  - How do agents determine their actions?

Complexity and Economic Modeling

- Most standard models in the economic literature rely on a very parsimonious approach (be careful, lots of recent developments!):
  - Agents of the same type are identical ('representative agent') or vary only with respect to a few parameters
  - Exchange of goods on frictionless spot markets
  - Agents have rational expectations
  - Behavior is determined according to some equilibrium concept based on (inter-temporal) optimization
- This approach yields workhorse models for policy analysis like Dynamic Stochastic Equilibrium Models (DSGE), Endogenous Growth Models, New Economic Geography Models,….

Complexity and Economic Modeling

- Useful approach for a large set of issues, but..
  - Set of strong assumptions, some with little empirical (micro-) foundation, also some conceptual problems (see Kirman, 1992)
  - Matching of empirical stylized facts often strongly depends on calibration of exogenous shocks, sometimes (seemingly model inconsistent) ad-hoc additions (Calvo pricing, rule-of-thumb consumers) are needed
  - Emerging properties, like contagion or rapid phase transitions typically cannot be captured
  - Focus often on long-run equilibria (e.g. balanced growth paths)
  - Policy makers are not always convinced…

J.-C. Trichet (ECB Central Banking Conference, Nov. 2010):

'*When the crisis came, the serious limitations of existing economic and financial models immediately became apparent.[…] Macro models failed to predict the crisis and seemed incapable of explaining what was happening to the economy in a convincing manner. As a policy-maker during the crisis, I found the available models of limited help. In fact, I would go further: in the face of the crisis, we felt abandoned by conventional tools. […]*

We need to deal better with heterogeneity across agents and the interaction among those heterogeneous agents. We need to entertain alternative motivations for economic choices. […] Agent-based modelling dispenses with the optimisation assumption and allows for more complex interactions between agents. Such approaches are worthy of our attention.'

Agent-based Approach to Economic Modeling

- Each relevant economic actor represented by an agent (many agents of identical type)
- Rule-based decision making by agents
- Agents interact through explicitly given interaction protocols (market rules, information flow channels, ..)
- Dynamics on the meso- (market/industry) and on the macro-level is generated by aggregating over the actions/stocks of all agents in the model

Generic Setup of an Agent-based Model

- For each agent of each type define:
  - set of decisions to be taken
  - set of internal states (e.g. wealth, skills, savings,..)
  - information agent might exchange with other agents
  - structure of each decision rule (inputs, how is decision made)
  - potential dynamic adjustment of internal states and decision rules
- Define interaction protocols for all potential interactions
- Define potential exogenous dynamics of parts of the economic environment (e.g. demand in partial market models, or technological frontier in macro models,..)
- Provide parametrization and initialization of all state variables

Main ‚Families' of Macro Agent-based Models (MABMs)

- Ashraf, Gershman, Howitt (AGH)
- Complex Adaptive Trivial Systems (CATS) (Delli Gatti, Gallegati et al.)
- Eurace@Unibi (EUBI) (Dawid et al.)
- Eurage at Genoa (EUGE) (Cincotti, Raberto et al.)
- Keynes meeting Schumpeter (KS) (Dosi, Fagiolo et al.)
- JAMEL Model (Seppecher, Salle)
- Lagom Model (Jaeger, Mandel,...)

The general architecture of a MABMs

- Agents: Households, Firms, Banks (and the public sector: Government and the central bank).
- Markets: C-goods, K-goods, labour (N), credit (L), assets.
- K-firms produce capital (K-goods) sold to C-firms.
- Both types of firms use bank loans to finance production and investment.

	Households	Firms	Banks
C-goods	H/C/d	F/C/s	
K-goods		F/K/d,s	
Labour	H/N/s	F/N/d	
Credit		F/L/d	B/L/s
Assets	H/A/d	F/A/s	

2. Model Design

i) Approaches for Designing Behavioral Rules

- How to model individual behavior?
- In ABMs (like in the real world) ‚locally constructive actions' (Sinitskaya & Tesfatsion, 2015) have to be implemented, constrained by their
  - interaction network
  - information beliefs
  - physical states.
- Hence, modeling in ABMs typically relies on behavioral rules and heuristics rather than on dynamic optimization under full information about model dynamics.
- Potential problem of ‚Wilderness of Bounded Rationality'.

2. i Approaches for Designing Behavioral Rules

Long history of discussion of this issue in Economics:

- Schumpeter(1911): all economic behavior is governed by rules, which are based on own and foreign experience...
- Alchian (1950): evolutionary selected rules should be considered as guiding rules for action.
- Friedman (1953): as-if argument
- Simon (1959): Satisficing „T*he entrepreneur might not care to maximize, but may simply want to earn a return that he regards as satisfactory..*“
- Cyert & March (1963) ‘A Behavioral Theory of the Firm’, consider operational procedures developed by actual firms

2. i Approaches for Designing Behavioral Rules

Long history of discussion of this issue in Economics:

- Nelson & Winter (1982): firm behavior based on ‘routines’ on different levels (operational, strategic)
- Lucas (1986): *’In general terms, we view or model an individual as a collection of decision rules […] Technically, I think of economics as studying decision rules that are steady states of some adaptive process, decision rules that are found to work over a range of situations and hence are no longer revised appreciably as more experience accumulates.’*
- Gigerenzer & Gaissmaier (2011), Gigerenzer (2016): ‘Ecological Rationality of Heuristics’.

2.i Approaches for Designing Behavioral Rules

Fixed decision rules

- Plausible heuristic rules (e.g. Nelson & Winter (1982), Ashraf et al. (2011), Assenza et al. (2015))
- Empirically observed decision Heuristics (e.g. Artinger & Gigerenzer (2017))
- Documented heuristic firm procedures (Dawid and Reimann (2004), Dawid and Harting (2011)): Management Science Approach

- Actions evolving over time
  - Individual learning (e.g. Arifovic (1994), Arifovic & Ledyard (2010))
  - Social learning (e.g. Dawid & Kopel (1996), Vriend (2000))

- Rules emerging over time (e.g. Dosi et al. (1999), Midgley et al. (1997), Arthur et al. (1997))

2.i Approaches for Designing Behavioral Rules

Let us consider two examples of decisions present in all MABMs:

1. Pricing/Quantity Decision by C-Firms

2. Savings Decision by Households

2.i Approaches for Designing Behavioral Rules

Fixed decision rules: E.g: Pricing and Production Quantity

- Plausible heuristic rules
  - Ashraf et al. (2011, AGH):
    - price: fixed mark-up, adjusted only if inventory/expected sales ratio becomes too small/large
    - quantity: expected sales plus inventory adjustment
  - Dosi et al. (2010, KS)
    - price: mark-up evolving based on firm's market share
    - quantity: proportional to expected demand

2.i Approaches for Designing Behavioral Rules

Fixed decision rules: E.g: Pricing and Production Quantity

- Plausible heuristic rules
  - Assenza et al. (2015, CATS)

Δ_{it} : difference btw. production and actual demand in t

Quantity:
$$Y^*_{i,t+1} = \begin{cases} Y_{i,t} - \rho\Delta_{it} & \Delta_{i,t} \le 0, P_{i,t} \ge P_t \\ Y_{i,t} - \rho\Delta_{it} & \Delta_{i,t} > 0, P_{i,t} < P \end{cases}$$

Price:
$$P_{i,t+1} = \begin{cases} P_{i,t}(1+\eta_{i,t+1}) & \Delta_{i,t} \le 0, P_{i,t} < P_t \\ P_{i,t}(1-\eta_{i,t+1}) & \Delta_{i,t} > 0, P_{i,t} \ge P_t \end{cases}$$

$\eta_{i,t}$: uniformly distributed in positive interval

2.i Approaches for Designing Behavioral Rules

Documented heuristic firm procedures:

- 'Management Science Approach'
  - For many types of firm decisions standard Management literature provide well documented approaches to tackle the problem.
  - Although often derived from some optimization considerations these approaches are typically heuristic.
  - Examples:
    - Pricing: economic value analysis, break-even analysis [Nagle et al. (2011)]
    - Production Quantity: Production Planning Heuristics: (Q,R)-policies, Stock-Out-Risk [Silver et al. (1998)]
    - Market Selection: BCG Matrix [Kotler & Keller (2009)]

2.i Approaches for Designing Behavioral Rules

Fixed decision rules: E.g: Pricing and Production Quantity

- Documented heuristic firm procedures:
- Pricing: economic value analysis [Nagle et al. (2011)] used in Eurace@Unibi model (e.g. Dawid et al. 2016, EUBI)
- Different steps:
  1. Market analysis:
     i) estimation of trend of overall market size
     ii) simulated purchasing surveys to estimate demand for different choices of the own price
  2. Determination of planned output for different prices.
  3. Production cost estimation for induced output quantities for different prices (taking into account potentially needed investments).
  4. Compare profits across considered menu of prices.

2.i Approaches for Designing Behavioral Rules

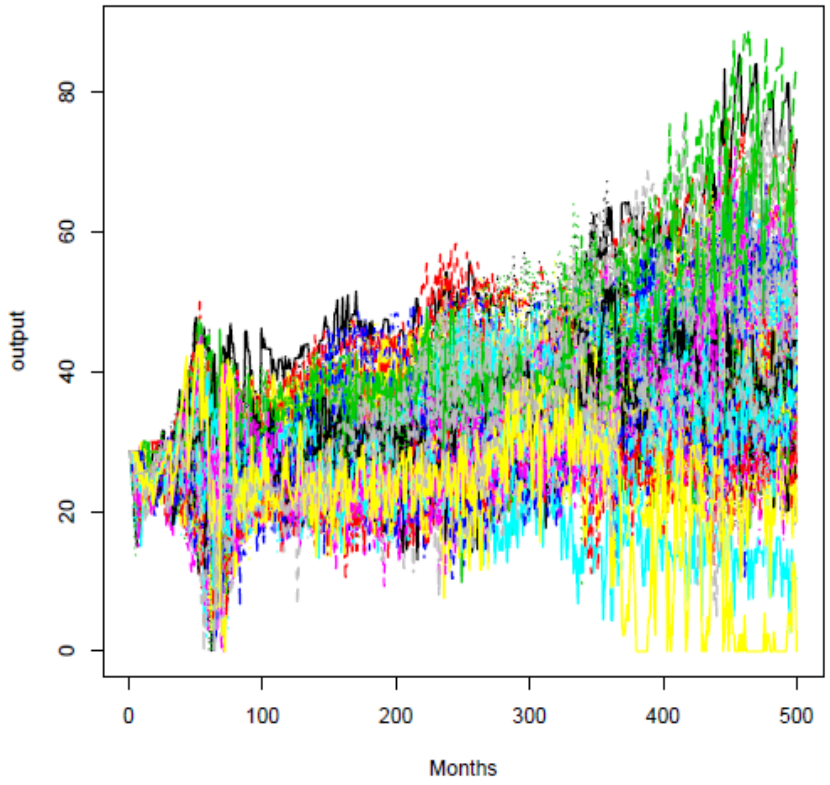
Fixed decision rules: E.g: Pricing and Production Quantity

- Documented heuristic firm procedures:
- Quantity Decision: Dawid et al. (2016, EUBI)
- Firms face uncertain demand (without knowing the exact structure of the demand generating process) and face potential stock-out costs
- -> standard problem in Operations Management ('Newsvendor Problem')
- -> Production Planning Heuristics in the OM literature: (Q,R)-policies
  - determine optimal stock-out probability (depending on stock-out costs, inventory costs)
  - estimate distribution of firm demand
  - determine target inventory level such that chosen stock-out probability is realized.

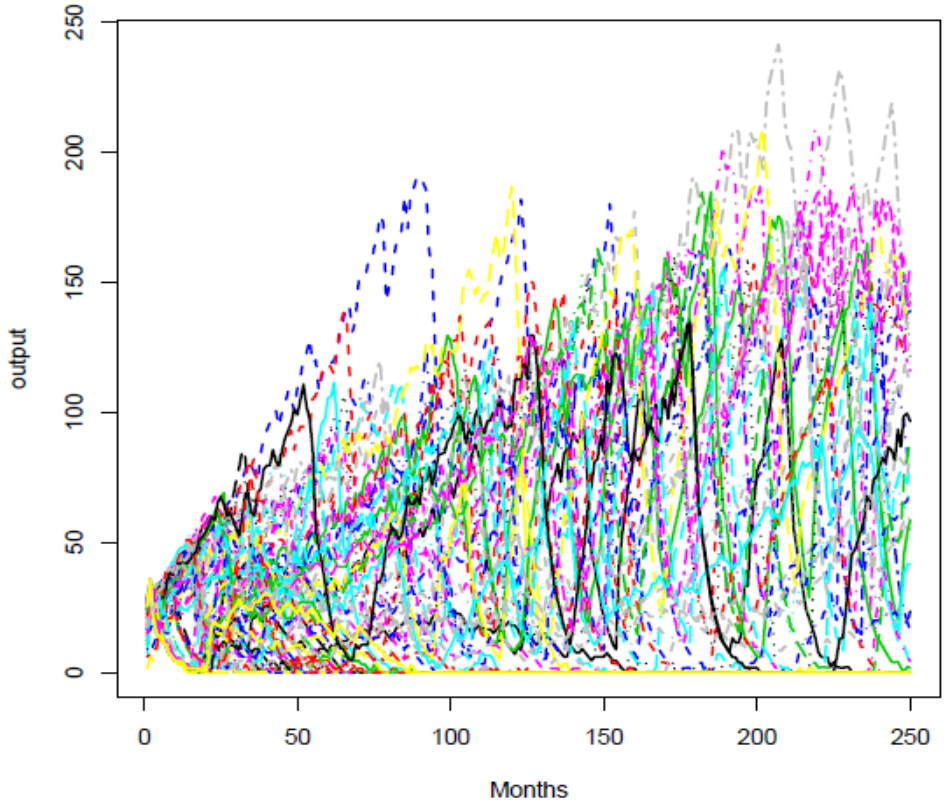
2.i Approaches for Designing Behavioral Rules

Fixed decision rules: E.g: Pricing and Production Quantity

- Comparison of dynamics of individual output with Eurace@Unibi pricing heuristic and const. mark-up:



endog. mark-up



const. mark-up

2.i Approaches for Designing Behavioral Rules

Fixed decision rules: E.g: Pricing and Production Quantity

- Empirically observed decision Heuristics
  - E.g. Artinger & Gigerenzer (2017): pricing heuristics of car dealers
    - Based on online observations and interviews with car dealers
    - Derive on this basis an aspiration level heuristic:

$$p(t) = (1+\alpha)\, p_{g,\min,t}\, \gamma^{m-1} \quad if\ (m-1)\beta \le t < m\beta$$

$p_{g,\min,t}$: minimum price in a group of matching cars

α : initial increase relative to minimum price on the market

β : time interval after which price is reduced if unsold

γ : factor by which price is reduced

    - Parameters estimated depending on market conditions

2.i Approaches for Designing Behavioral Rules

Fixed decision rules: E.g: Households Consumption Budget

- AGW, CATS: fixed fraction of wealth
- Eurace@Unibi, LAGOM: buffer-stock rule: mean past income + adjustment wrt wealth/income target ratio (inspired by Deaton (1991), Carroll & Summers (1991)).
- JAMEL: buffer stock rule with target ratio depending on consumer sentiment.
- KS: HHs consume their entire income.

2.i Approaches for Designing Behavioral Rules

Actions evolving over time:

- Action is not determined by a rule, but chosen ‘as such’ by the firm every period based on own (and others) past success of different actions.
- Typical setup:
  - In each period firm selects (stochastically) from a population of action values
  - Each action has a fitness (or strength) which influences selection probability
  - The action’s fitness and the set of considered actions is updated over time based on their (relative) fitness.
- Prime examples of such procedures:
  - Reinforcement Learning
  - Genetic Algorithms
  - Individual Evolutionary Learning
- Comparison of generated dynamics with that of human subject experiments!

2.i Approaches for Designing Behavioral Rules

Rules evolving over time:

- Different approaches in the literature:
  - Classifier Systems
  - Genetic Programming
  - Neural Networks
- Large functional flexibility, weak ex-ante assumptions about (functional) form of the rule have to be made.
- Potential ‘black-box’ problem: emerging rules not straight-forward to interpret.
- Hard to link to empirical/experimental evidence on updating of rules.

2.ii Interaction Protocols

- Wide variety of potential approaches to model interactions on different markets:
  - Goods Markets: posted prices, individual bargaining, auctions, spot markets
  - Financial Markets: order books, market makers, spot markets
  - Labor Markets: search and matching, posted wages, bargaining
  - Electricity Markets: double auctions, clearing houses
  - ...
- Additionally, agents might interact by e.g. exchanging information (social networks, spatial structure,..)
- Most suitable choice of interaction protocols and detail of institutional representation depends on strongly on underlying research question!

Coffee Break

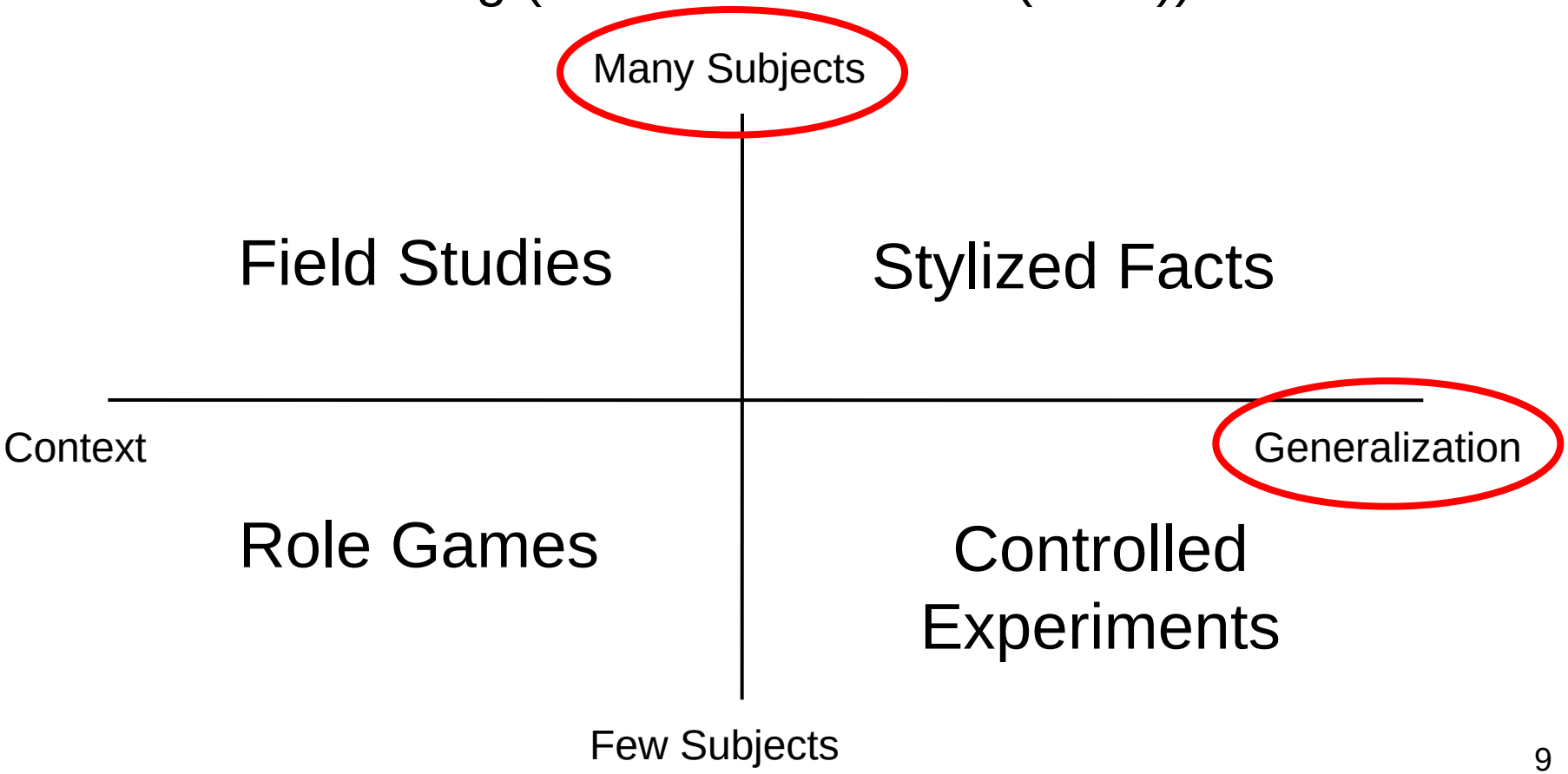
3. Empirical Validation and Calibration

- Main challenges:
  - Path dependent and stochastic, complex dynamics of simulation output
  - Missing systematic concept of ‘good match with empirical data’
  - The number of parameters might be large

- Main approaches:
  - Indirect calibration: reproducing stylized facts (see e.g. Dosi et al. (2010, 2013, 2014), Dawid et al. (2014, 2018))
  - Calibration, systematic search in the parameter space (Grazzini et al., 2015, 2017), Barde (2016), Barde & van der Hoog (2017), Guerini & Moneta (2017), Lamperti et al. (2017).

3. Empirical Validation and Calibration

- Different approaches to combine empirical information and AB modeling (Janssen & Ostrom (2006)):



3. Empirical Validation and Calibration

- Indirect Calibration Approach (see Windrum et al. 2007)
  - Identify set of stylized facts to be reproduced/explained (industry/macro level)
  - Incorporate empirical and experimental evidence about principles underlying real-world behaviors
  - Restrict parameter space and initial conditions to sets where simulation output matches stylized facts
  - Deepen understanding of causal mechansisms that underlie the studied stylized facts

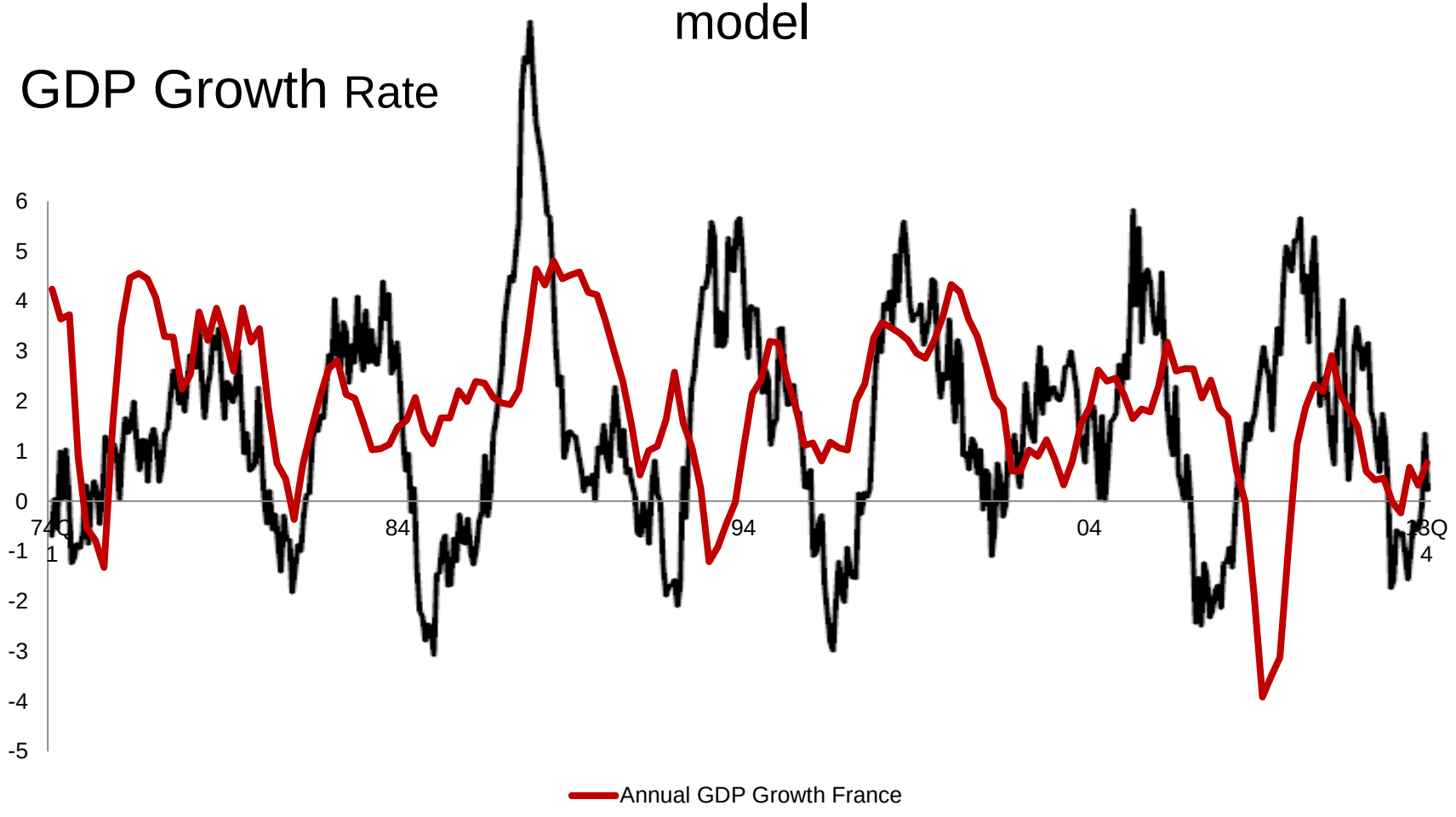
- Calibrated model can be used to explore additional stylized facts (to be tested empirically) or to study effects of institutional changes, policy measures,…

3. Empirical Validation and Calibration

- Reproducing Empirical Stylized Facts (ESFs)
  - Disciplining effect for model and parameter choices
  - Adds credibility for non-economist audiences
  - Ability to reproduce ESF of different types and on different levels of aggregation -> one of the selling points of ABMs
  - What does reproduction exactly mean?
  - Bias in selecting ‘key stylized facts’?

3. Empirical Validation and Calibration

Example: some stylized facts reproduced by the Eurace@Unibi model



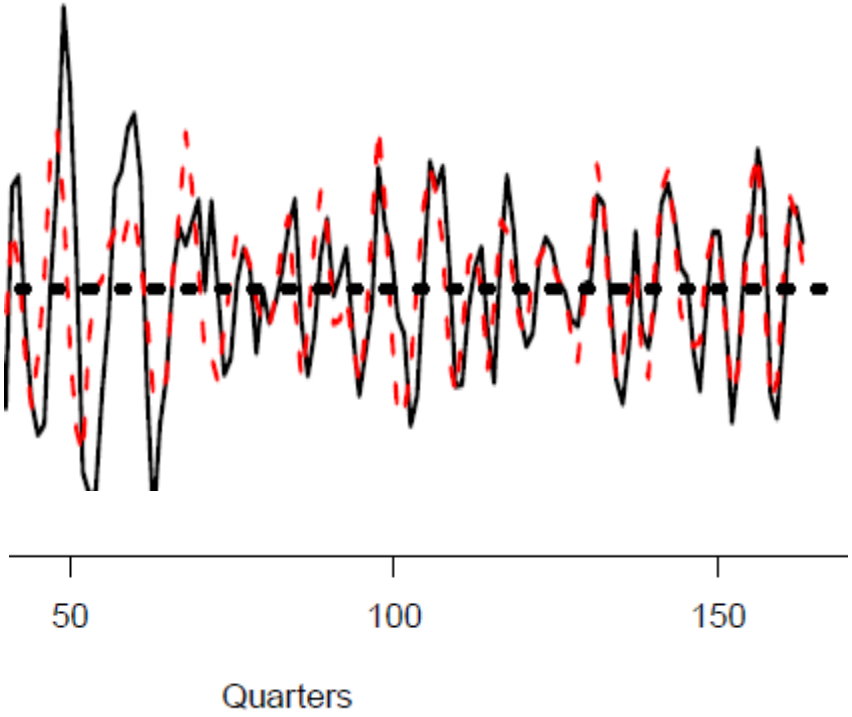
3. Empirical Validation and Calibration

- How to quantify, whether growth rate dynamics in the model is ‚close' to observations in the data?
  - Compare means, distribution, autocorelation structure
  - e.g. Eurace@Unibi vs. US Data (1955 – 2001):

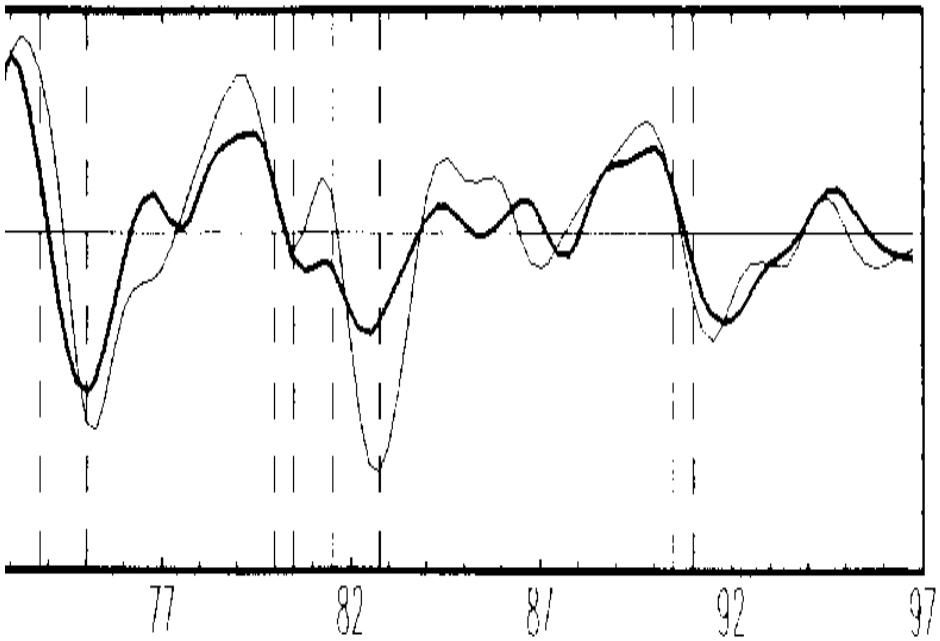
	Eurace@Unibi	US- Data
Av. Growth Rate	1.6%	1.8%
Volatility	1.54%	1.66%
One-quarter Autocorelation	0.9	0.86

3. Empirical Validation and Calibration

Dynamic Properties and Stylized Facts: Output and Consumption



Eurace@Unibi
(black: output, red: cons.)

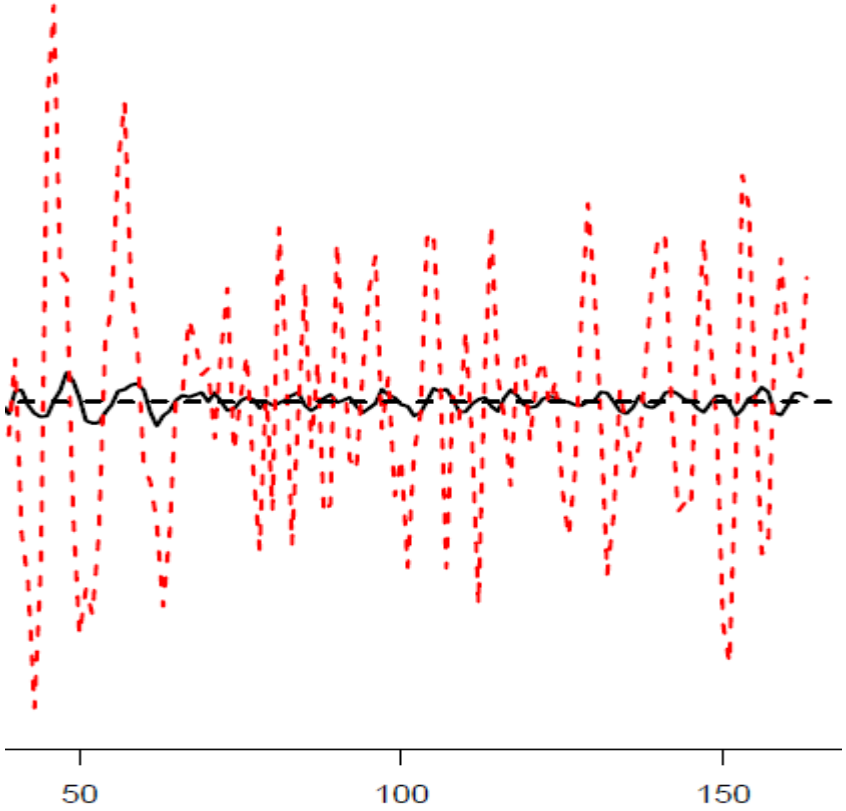


US Data (Stock & Watson, 1999)
(light: GDP, bold: cons.)

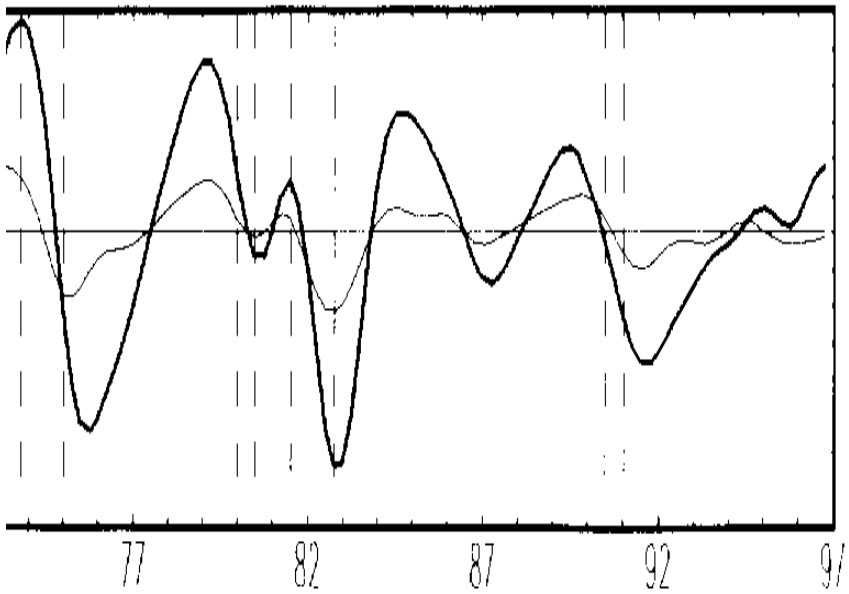
bandpass filtered

3. Empirical Validation and Calibration

Dynamic Properties and Stylized Facts: Output and Investment



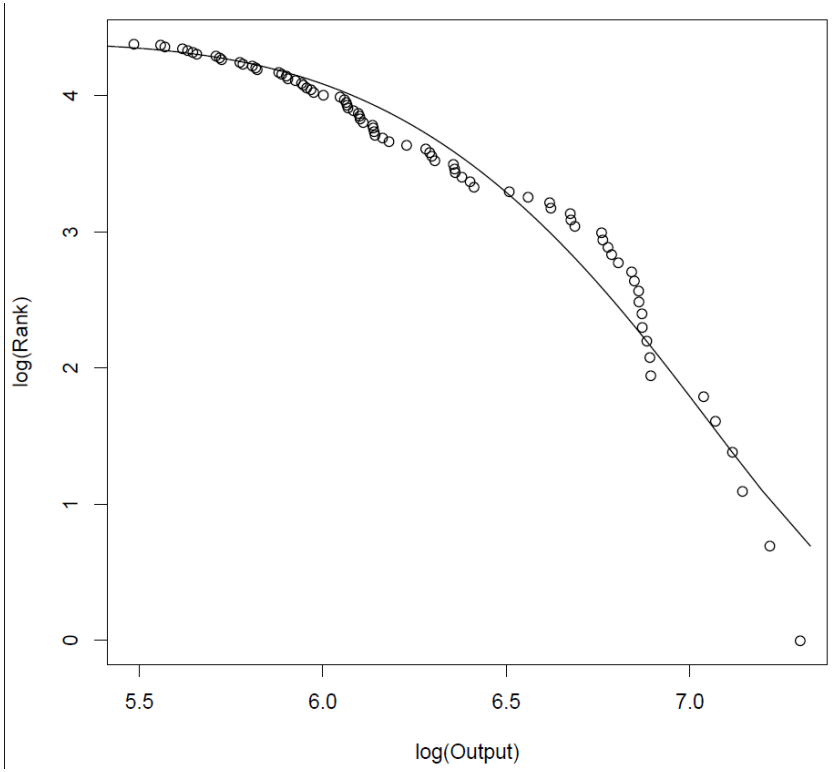
Eurace@Unibi
(black: output, red: inv.)

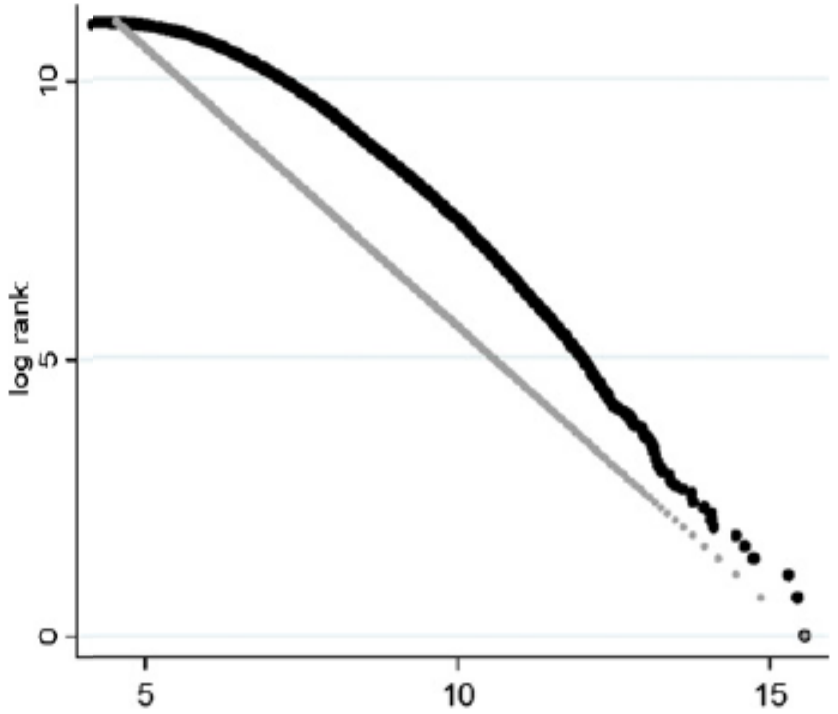


US Data (Stock & Watson, 1999)
(light: GDP, bold: inv.)
bandpass filtered

3. Empirical Validation and Calibration

Dynamic Properties and Stylized Facts: Firm Size Distribution (Sales)



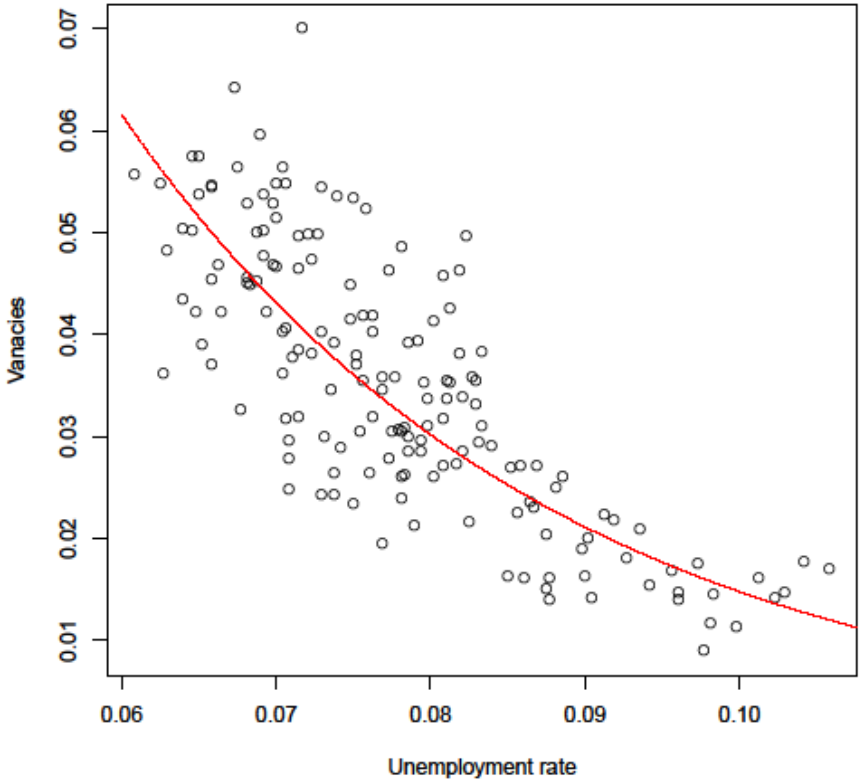


Eurace@Unibi

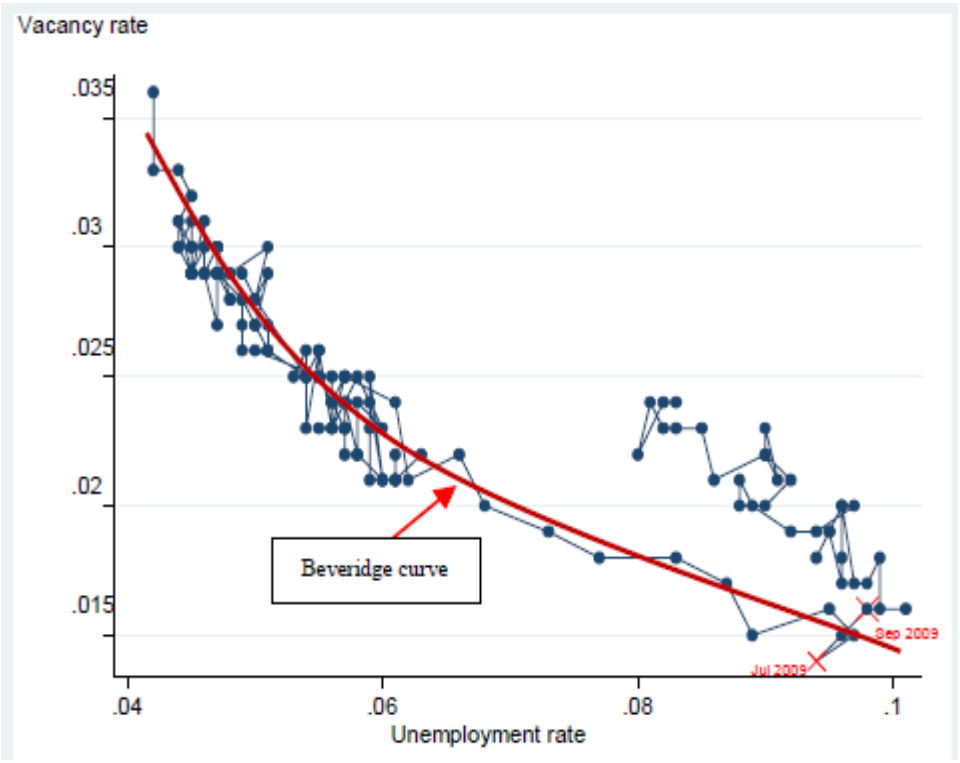
Spanish Data (Segarra/Teruel (2012))

3. Empirical Validation and Calibration

Dynamic Properties and Stylized Facts: Beveridge Curve



Eurace@Unibi



U.S. (2001-2012)

(Ghayad & Dickens, 2012)

3. Empirical Validation and Calibration

Estimation, calibration, systematic search in the parameter space:

- General challenge: find parametrization of the model, such that its output matches ‘optimally’ the empirical data.
- General approaches:
  1. Bayesian: start with some a-priori distribution in the parameter space and update based on available empirical data (Grazzini & Richiardi, 2017)
  2. Non-Bayesian: search systematically in the state space and compare different parameter constellation based on some ‘distance measure’ between simulation output and data.

3. Empirical Validation and Calibration

Main challenges for estimating/calibrating ABMs

- Which distance measure?
  - Simulated method of moments (Gilli & Winker, 2003)
  - Simulated minimum distance (Grazzini & Richiardi, 2015)
  - Context Tree Weighting: estimated probability of data based on conditional state-transition probabilities from the model (Barde, 2016)
  - GSL-div: discretize time series output to finite set of ‘symbols’ and compare frequency of symbols in subintervals (Lamperti, 2017)
  - Generate Stoch.-Vector-Autoregressive (SVAR) estimation of model and data and determine the number of coefficients with equal sign (Moneta & Guerini, 2016)

3. Empirical Validation and Calibration

Main challenges for estimating/calibrating ABMs

- Computational Effort
  - In order to calculate the distance between the model and the data, typically large batch runs are needed for each considered parameters setting
  - -> for large ABMs computational effort might be prohibitively large
  - -> ‘meta models’ might be used for estimation/calibration: simple statistical representations of the ABM capturing the main qualitative properties of the generated data, in particular the impact of certain parameter changes

3. Empirical Validation and Calibration

Main challenges for estimating/calibrating ABMs

- Sampling of parameter space:
  - ABMs often have many parameters -> simple grid search in the high-dimensional parameter space often not feasible (‘curse of dimension’)
  - More efficient sampling methods can be used; should have space-filling and orthogonality properties: e.g. Nearly Orthogonal Latin Hypercubes (Salle & Yildizoglu, 2014)

3. Empirical Validation and Calibration

Example: Barde & van der Hoog (2017)

- Calibration of Eurace@Unibi model using OECD data from 30 countries.
- Focus on 3 output variables (unemployment rate, output growth rate, inflation rate) and 8 key parameters.
- Comparison of simulated and empirical time series based on the Markov Information Criterion:
  - discretize state space
  - estimate conditional state-transition probabilities (context tree weigthing)
  - calculate score of empirical time series

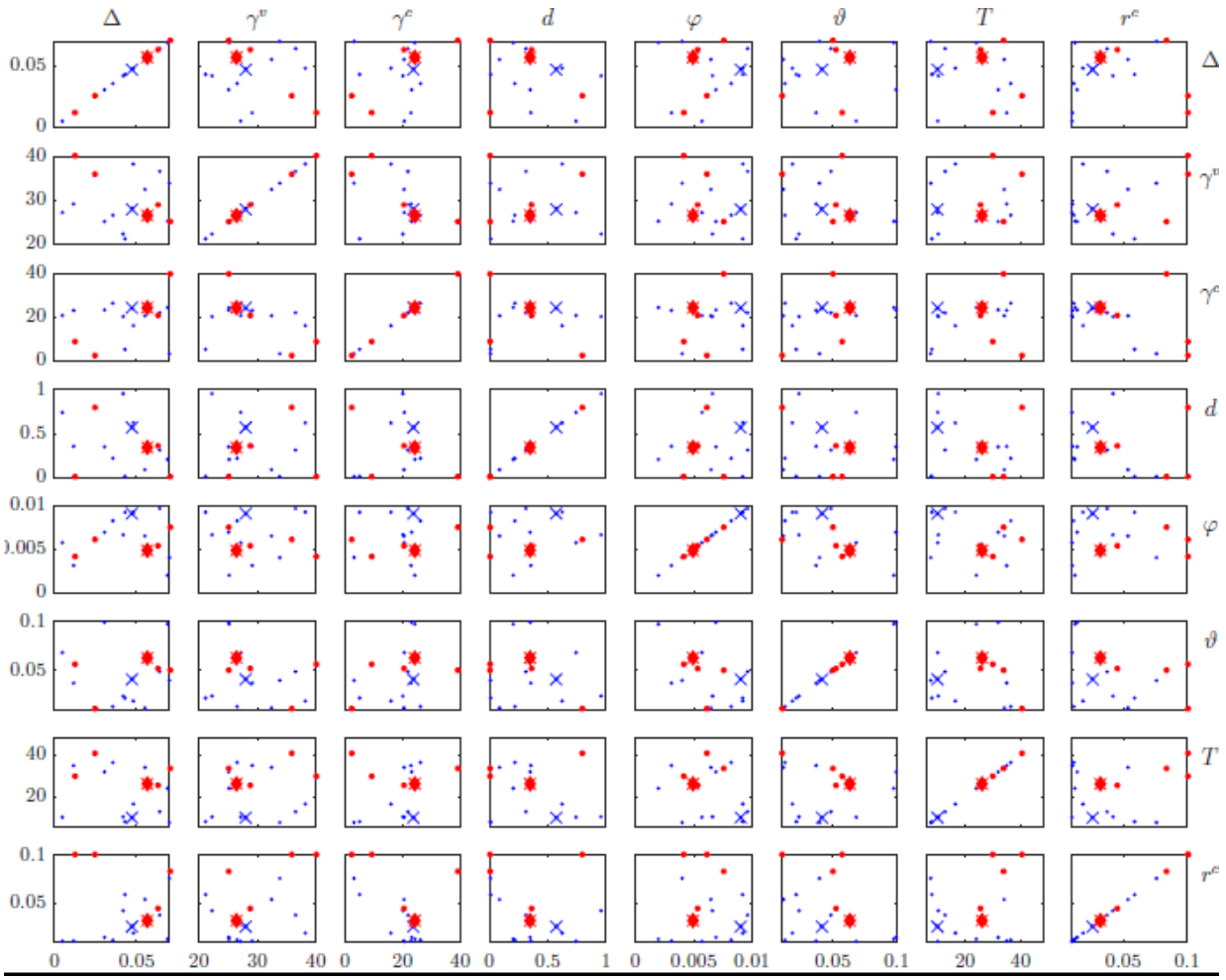
3. Empirical Validation and Calibration

Example: Barde & van der Hoog (2017): Eurace@Unibi

- Steps of the procedure:
  1. Generate a set of 513 parameter vectors using Nearly-Orthogonal Latin Hypercube (NOLH) sampling.
  2. For each parameter set run the model 1000 times and save time series of the 3 target variables for all 513 * 1000 runs.
  3. Determine for each parameter setting conditional transition probabilities (context trees) using 99% of the runs.
  4. Validate the obtained transition matrices using the remaining 1% of the runs.
  5. For each country determine the ‚score' under the transition probability derived for each parameter set.
  6. Determine for each country parameter set with the highest score (best fit).
  7. [Search for high potential parameter sets between the sampled points using Kriging and determine score of these sets.]

3. Empirical Validation and Calibration

Results for Germany



4. Analysis of Simulation Output

- Each run of the simulation model is one realization of a stochastic process. Observed dynamics might change from run to run even if all policy parameters remain unchanged.
- -> a change in a policy parameter can (like in the real world!) only influence the dynamics in a statistical sense (i.e. change the distribution of the outcomes)

4. Analysis of Simulation Output

- To make sensible statements about the effects of changes of parameters or the introduction of some policy measure a sound statistical analysis is needed!
- Most common approaches:
  - Graphical analysis comparing boxplots or means/medians with some confidence band for different parameters.
  - Statistical tests on equality of means of some meaningful indicators under different parameters: e.g. Wilcoxon Signed Rank Test.
  - Estimating dynamic statistical models: e.g. penalized splines

4. Analysis of Simulation Output

- Simple Example: N runs of ABM across different parameter settings, policy effect (0/1) varying over time.
- To represent the ABM runs consider the following data generating process:

$$Y_{t,p,i} = \sin(2\pi t/T) + \kappa_i \upsilon_{t,p,i} + \alpha (t/T)^2 I_{[pol=1]} + \varepsilon_{t,p,i}$$

$\upsilon_{t,p,i}, \varepsilon_{t,p,i}$: i.i.d, Gaussian with mean 1, STD: $\sigma_\upsilon, \sigma_\varepsilon$

$\alpha > 0$: strength of policy effect

κ_i : run specific effect, uniform in [0,1]

4. Analysis of Simulation Output

- How can we identify the policy effect?
  - Graphical analysis showing evolution of mean and confidence bands with/without policy.
  - Boxplots of aggregated indicator (time average for each run)
  - Statistical tests on equality of medians with/without policy: Wilcoxon Signed Rank Test.
  - Estimating dynamic penalized splines model (simple GAM in R)

$$Y_{t,p,i} = s_0 + s(t) + I_{[pol=1]} s_{pol}(t) + \varepsilon_{t,p,i}$$

$s(t), s_{pol}(t)$: weighted sums of cubic basis functions

  - More advanced approach to capture run specific effects and potential path dependencies (GAMM in R)

$$Y_{t,p,i} = s_0 + s(t) + I_{[pol=1]} s_{pol}(t) + \eta_i^0 + \eta_i^1 t + \varepsilon_{t,p,i}$$

4. Analysis of Simulation Output

- Gain a clear understanding of the economic mechanisms:
  - search for causal chains by considering time series of micro/meso level variables
- Check robustness of parameter/policy effects
  - vary key parameters of the model and carry out the policy experiments across these variations
  - explore the ‚limits' of the range of parameters where the obtained results qualitatively stay intact

Coffee Break

5. Policy Analysis

- Substanial increase in MABM work with policy focus since 2008:
  - Feedback between real and financial dynamics became policy focus.
  - Systemic considerations, network and contagion effects.
  - 'Workhorse MABMs' have been established as platform for policy analysis.
- Key policy domains:
  - Fiscal Policy
  - Monetary Policy
  - Financial Regulation and Crisis Resolution
  - Labor Market Policies
  - (Regional) Growth, Convergence and Cohesion Policy

5. Policy Analysis

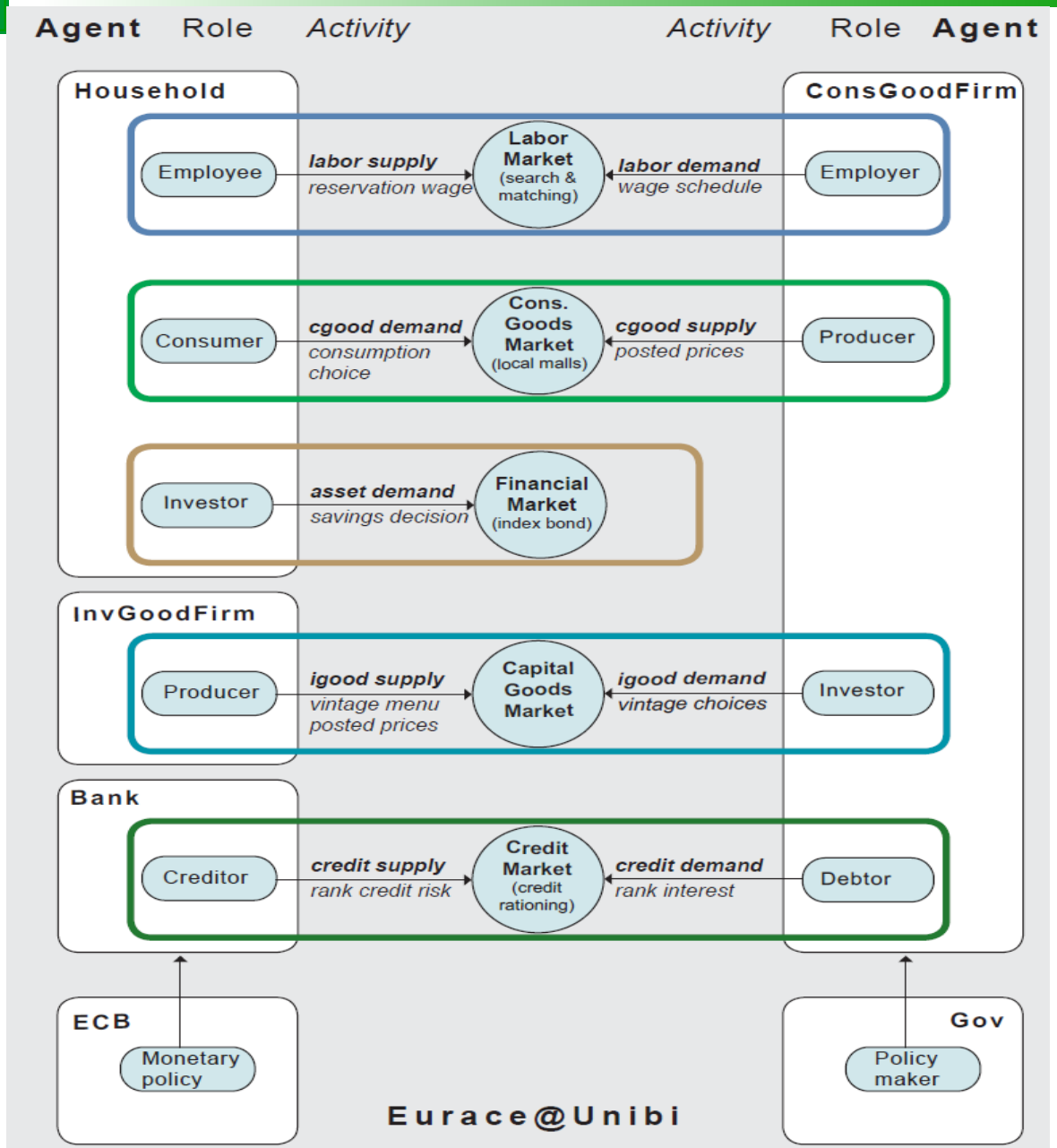
- An illustrative example: the Eurace@Unibi model

- **Main focus:** improve understanding of interplay between
  - technological progress and diffusion
  - skill dynamics
  - investment
  - credit market dynamics
  - growth and inequality

5. Policy Analysis

Main features of the Eurace@Unibi model

- Networks and geographical structure
  - Regions located on grid, agents assigned to regions
  - Distribution of agents and their characteristics might differ between regions
  - Agents linked through firm-bank and social networks
- Empirical micro-foundation of agents' decision rules
  - relevant management literature (‘Management Science approach’)
  - empirical consumer behavior literature
- Explicit representation of interaction protocols on markets and regulatory institutions.


Agent
Role
Activity
Activity
Role
Agent
Household
ConsGoodFirm
Employee
labor supply
reservation wage
Labor Market
(search & matching)
labor demand
wage schedule
Employer
Consumer
cgood demand
consumption choice
Cons. Goods Market
(local malls)
cgood supply
posted prices
Producer
Investor
asset demand
savings decision
Financial Market
(index bond)
InvGoodFirm
Producer
igood supply
vintage menu
posted prices
Capital Goods Market
igood demand
vintage choices
Investor
Bank
Creditor
credit supply
rank credit risk
Credit Market
(credit rationing)
credit demand
rank interest
Debtor
ECB
Monetary policy
Gov
Policy maker
Eurace@Unibi

5. Policy Analysis

Consumption Good Production

- Production using (vintage structured) capital and labor.
- Complementarity between quality of capital goods and level of specific skills of workers.
- Workers acquire specific skills on the job when working in a firm with high quality (physical) capital.
- Workers differ wrt to their speed of on the job learning (general skills).

5. Policy Analysis

Technological Change and Diffusion

- Investment good producer (IGP): offers range of investment goods with different quality (vintages) (at differentiated prices).
- New vintages with improved quality are added to the product range following stochastic innovation cycles.
- Vintage choice of Consumption good producers (CPG):
  - logit choice model based on estimated future productivity of the vintage over a planning horizon
  - depends on the skills of the firm's employees (Piva & Vivarelli, 2009).

5. Policy Analysis

Consumption Goods Market

- Consumption goods producers offer (and store) goods at market outlets (‚*malls*‘) at posted prices.

- Once every year CGPs adjust prices:
  - profit oriented pricing rules relying on *simulated purchase surveys, see Nagle & Hogan, 2006*)

  -> endogenous mark-ups.

- Once every month CGPs decide on quantities to be delivered to the mall:
  - based on standard OM heuristics relying on estimates of the demand distribution

5. Policy Analysis

Labor market

- Firms post job vacancies based on planned output.
- Simple search and matching protocol.
- Wage offers vary across general skill groups.
- Wage offer: $w_{i,t,g} = w_{i,t}^{base} \overline{b}_{i,t,g}$
- Workers take into account commuting costs when comparing offers: $w_{i,t,g}(1-c)$
- -> Firms might be rationed on the labor market and there is frictional unemployment.

5. Policy Analysis

Credit Market

- Firms apply for bank loans if internal resources do not suffice to cover expenses.
- Banks are constrained in giving out loans and accepting risks by capital and liquidity requirements.
- Interest rate for loans determined as ECB rate plus (risk dependent) mark-up
- Central-bank provides standing facilities to banks at a base rate.
- Firms and households make deposits at bank at an interest rate marked-down from the base rate.

5. Policy Analysis

Government

- Collects income tax
- Pays out unemployment benefits
- Finances policies (e.g. subsidies)
- Tax rates in all regions are dynamically adjusted to reach a balanced budget

5. Policy Analysis

Some Technical Issues

- Asynchronous decision making and ‘day to act’ of agents
- Closedness of the model is ensured through the use of balance sheets for all agents.
- The model is implemented in FLAME (Flexible Large Scale Modelling Environment)

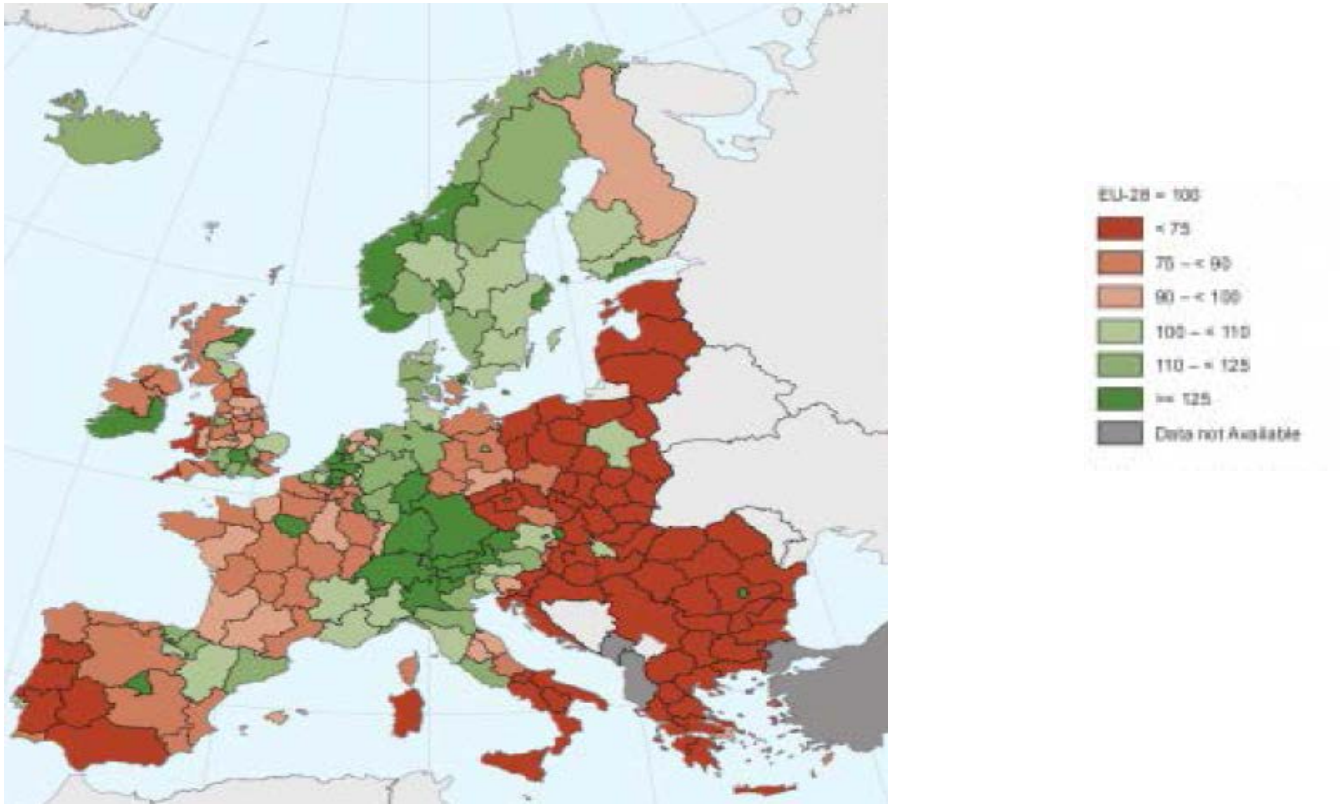
Policy issuess adressed using the Eurace@Unibi model:

- Policies fostering growth of lagging regions (with public debt trouble) in an economic union (Dawid et al., 2017).
- Impact of different kinds of bank regulations (van der Hoog & Dawid, 2017, van der Hoog, 2017)
- Effectiveness of EU cohesion policies (Dawid et al., 2013, 2014)
- Effect of social networks on wage inequality (Dawid & Gemkow, 2014)
- How is technological change and growth affected by stabilizing fiscal and regulatory policies? (Harting, 2015)
- Impact of spatial frictions on factor and goods markets for economic convergence and growth (Dawid et al., 2011)
- Implications of different spatial distributions of policy measures (Dawid et al. 2008, 2009)

5. Policy Analysis

Cohesion Policy in the EU

- Facilitation of convergence of per-capita income and productivity among European regions is one of the main goals of EU (economic) policy (about 35% of EU Budget spent for cohesion policies).



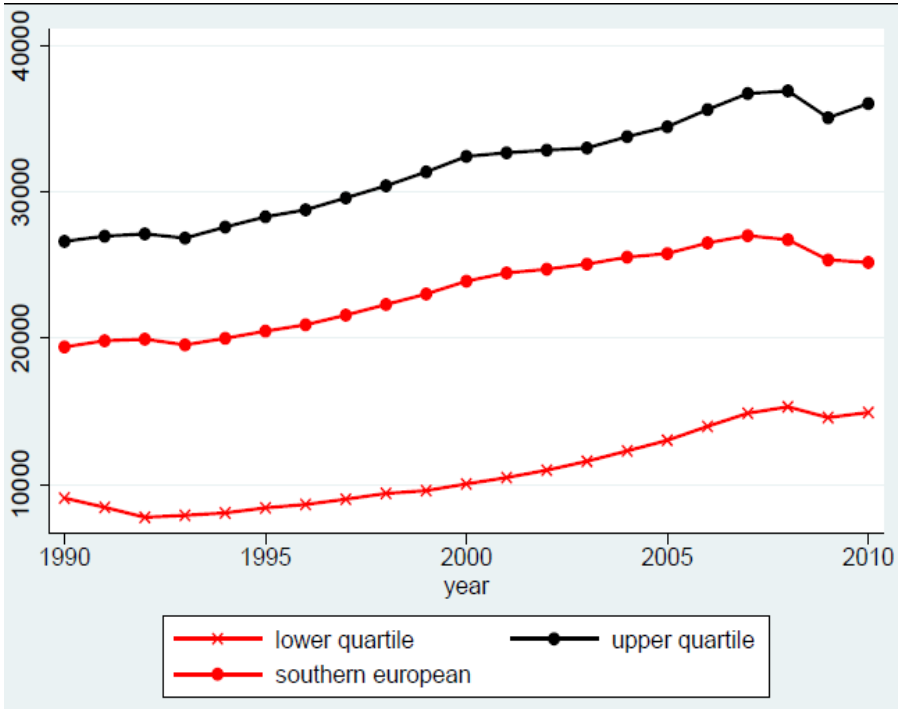
5. Policy Analysis

Policy Example: Cohesion Policy (Dawid, Harting and Neugart, 2013, 2014)

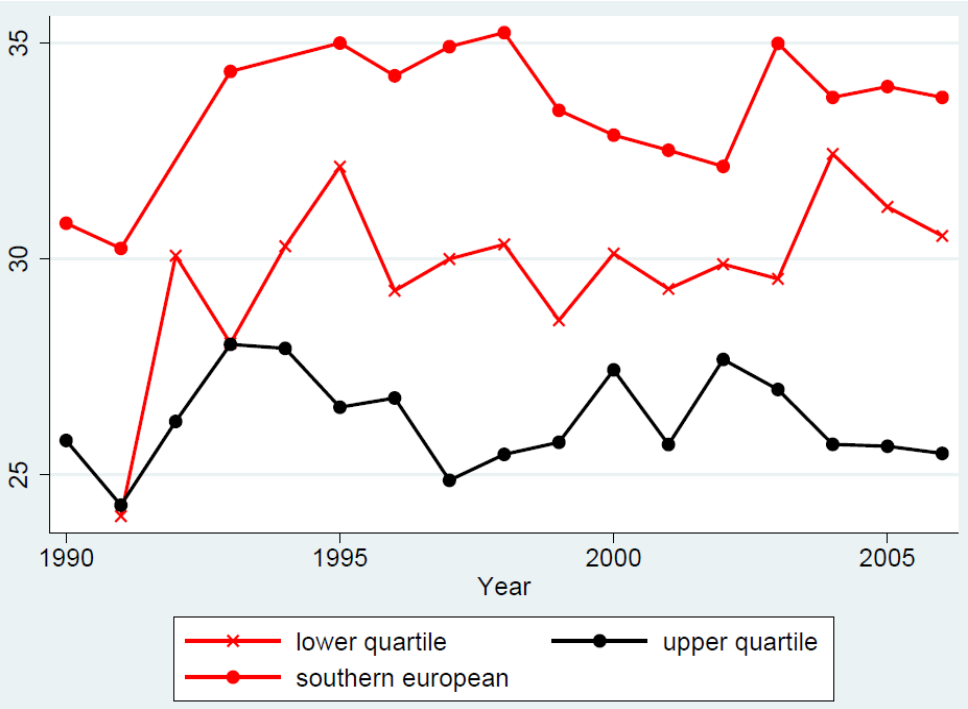
- 2 main policy instruments:
  1. European Regional Development Fund (€ 201 bn, 2007-2013)
     - Direct aid to investments in companies
     - Infrastructure linked notably to research and innovation
     - …
  2. European Social Fund (€ 76 bn, 2007-2013)
     - Strengthening human capital
     - Adapting workers and enterprises
     - ...

5. Policy Analysis

- Regional differences persist not only with respect to per-capita GDP but also wrt (intra-regional) income inequality:



Per-capita GDP



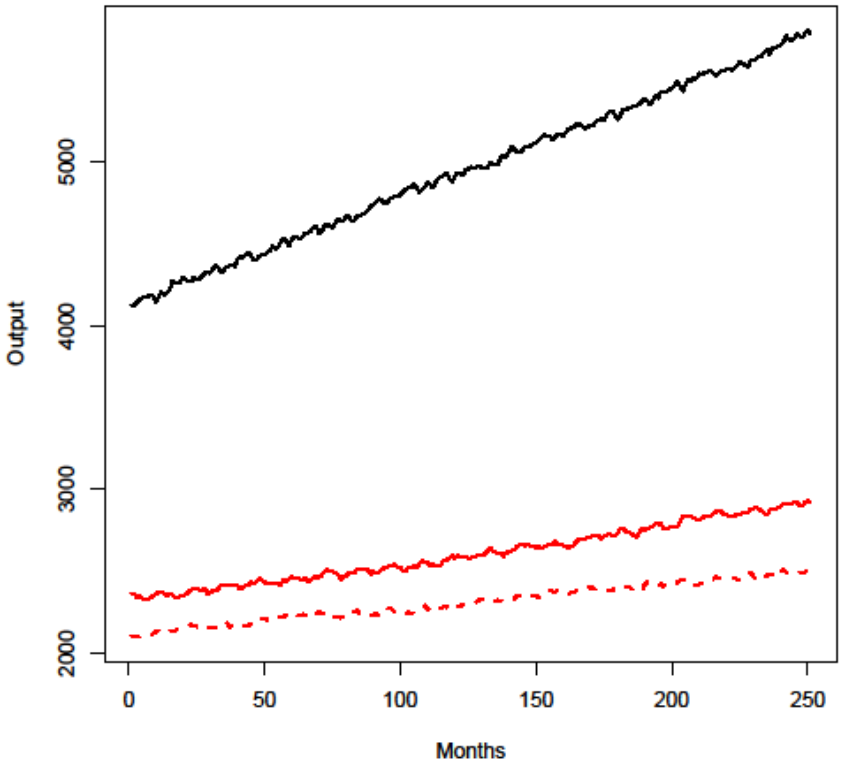
Gini-coefficient

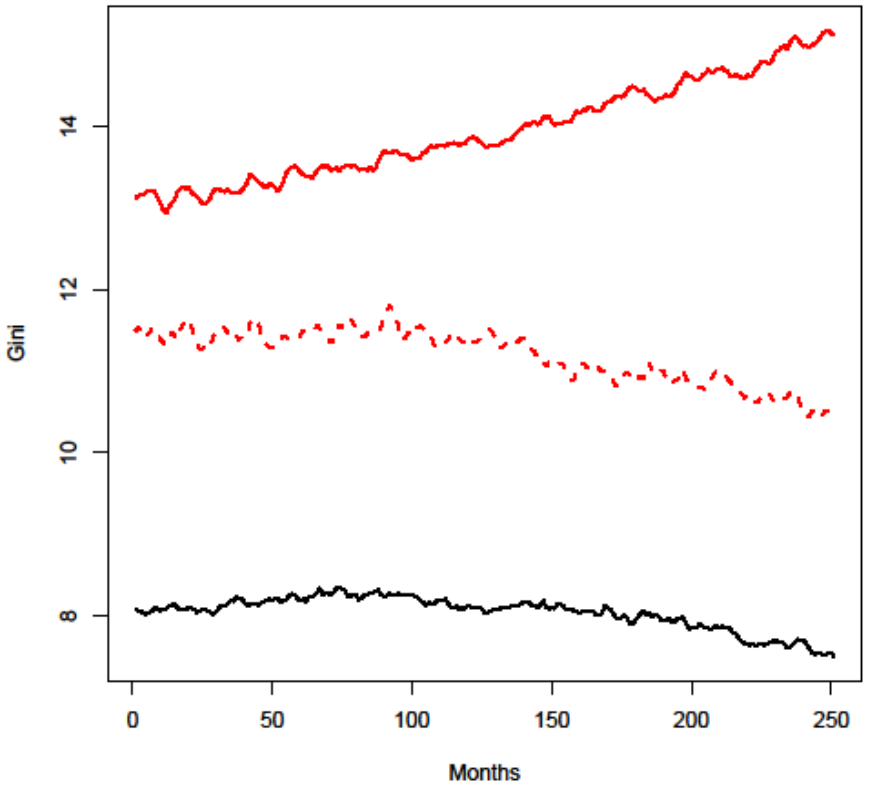
5. Policy Analysis

- Consider 2 region version of Eurace@Unibi: R1 (high tech), R2 (low tech)
- In comparison with (high tech) R1 region R2 has
  - lower initial average quality of physical capital in firms
  - lower initial average specific skills of workers
  - lower distribution of general skills of workers
- Integrated consumption good market but separated labor markets.
- 2 institutional settings are considered
  1. flexibility of labor market in R2 identical to that of R1 (replacement rate, adjustment speed of reservation wage of workers when unemployed)
  2. flexibility of labor market in R2 higher

5. Policy Analysis

- Eurace@Unibi replicates qualitative patterns of evolution of per-capita output and Gini





Output Income Gini

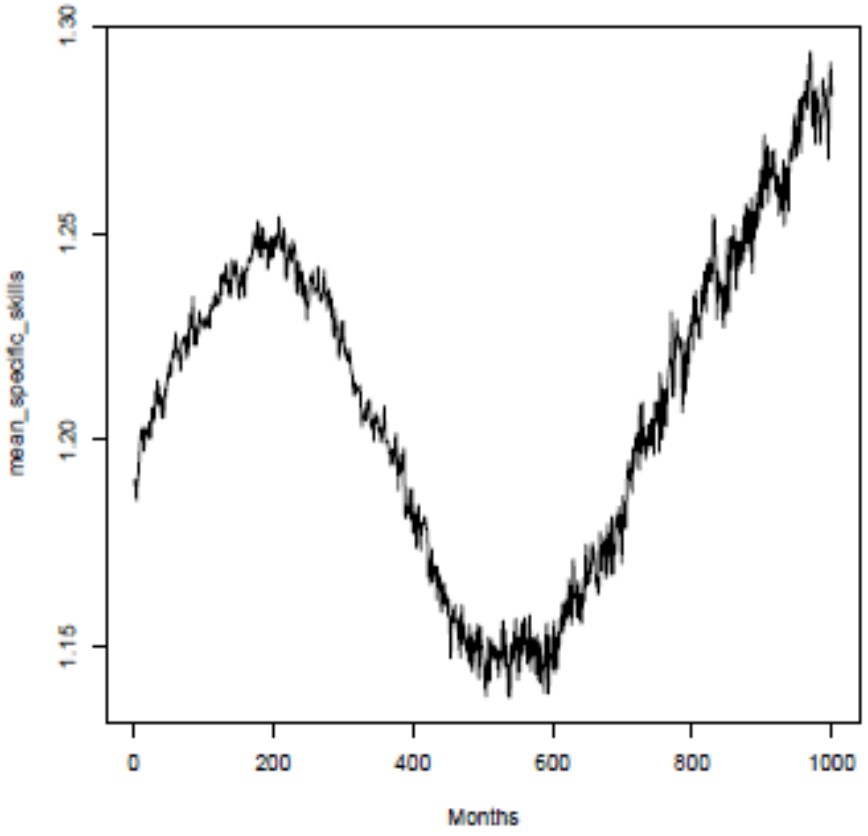
(black: R1, red: R2 inflex LM, red dotted: R2 flex LM)

5. Policy Analysis

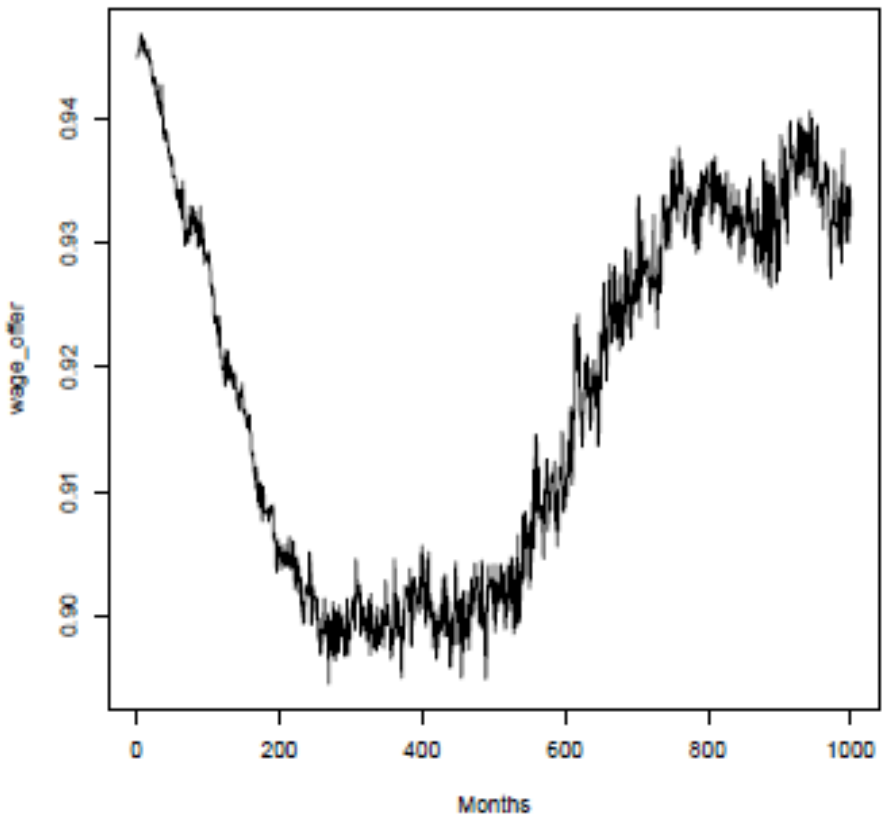
Firm Heterogeneity in the Low-Tech Region(inflex LM)

Ratio (high-prod./low-prod. firms) in R2 of average values of

specific skills



base wage offer



5. Policy Analysis

- Policy question (inspired by ERDF measures): how important is it that investment subsidies are technologically ‚directed' ?
- Considered Technology (Tech) Policy: Firms in R2 receive subsidies (20% of price) when acquiring physical capital

  Policy tries to incentivize firms to buy the best available capital vintage.

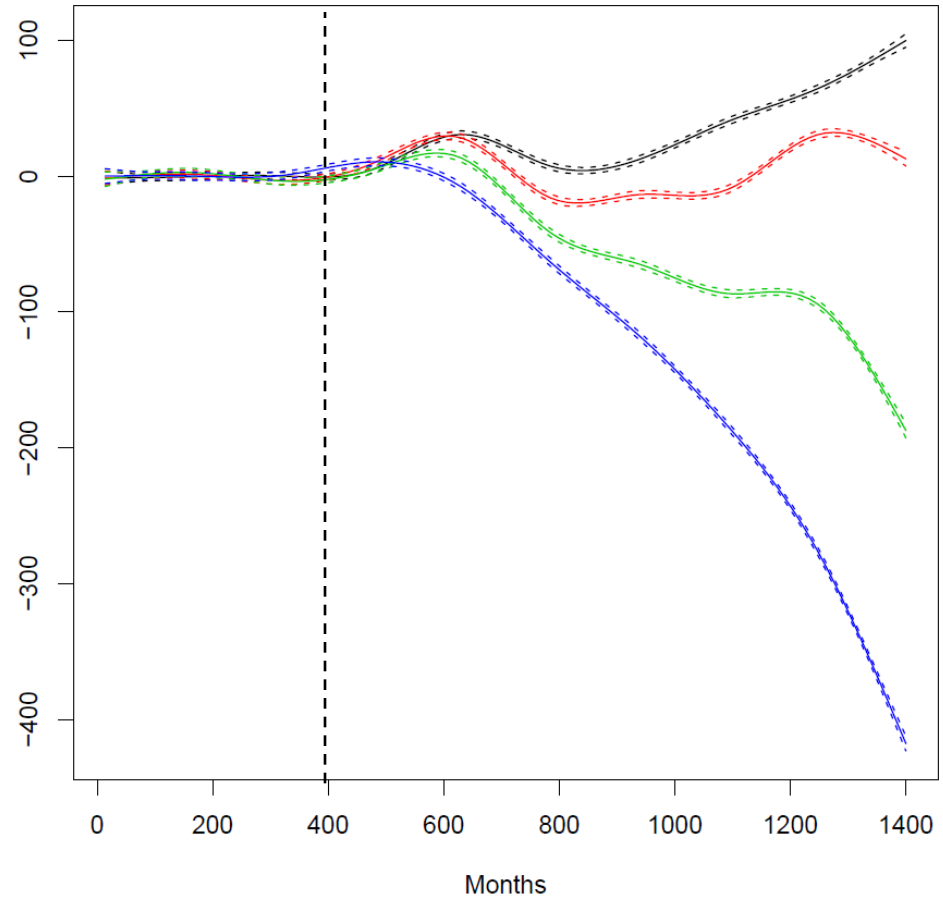
  α: fraction of firms in R2 that are induced by the policy to purchase highest vintage: $\alpha = 0.1, 0.2, 0.3$

- What is the effect of α on the effectiveness of the policy in fostering convergence between regions?

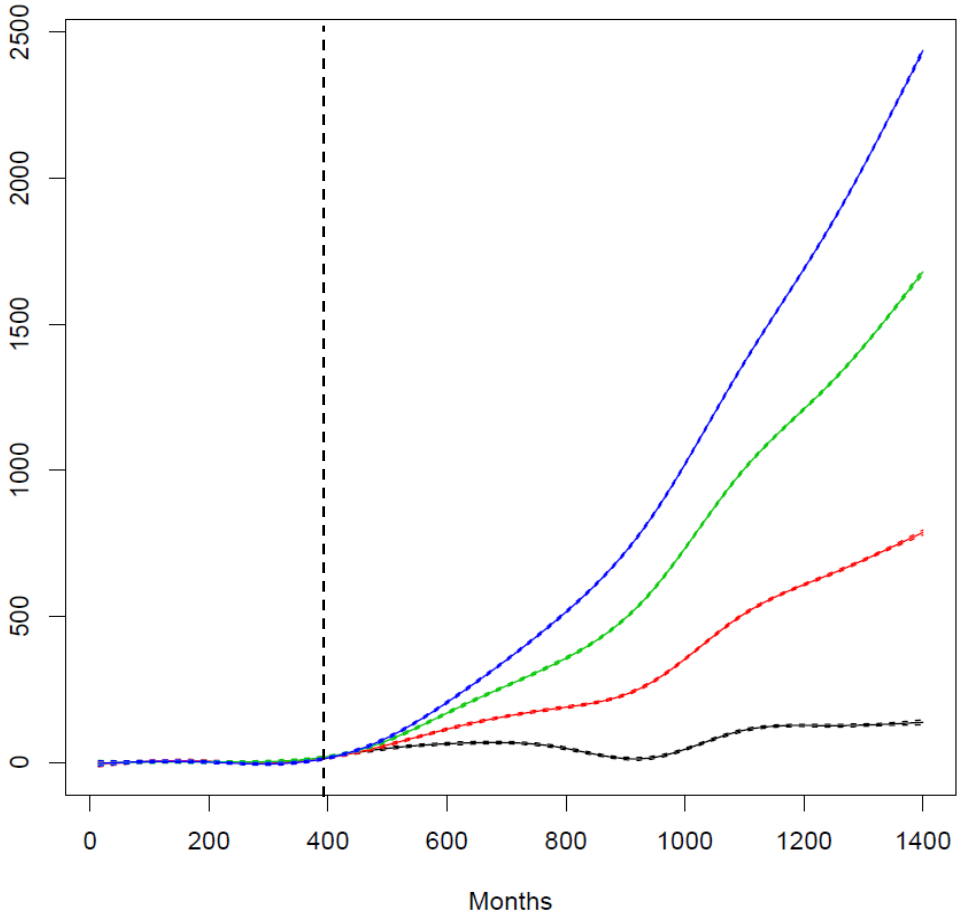
5. Policy Analysis

Output (sep. & inflex LM)

(black: α=0, red: α=0.1, green: α=0.2, blue: α=0.3)



Region 1



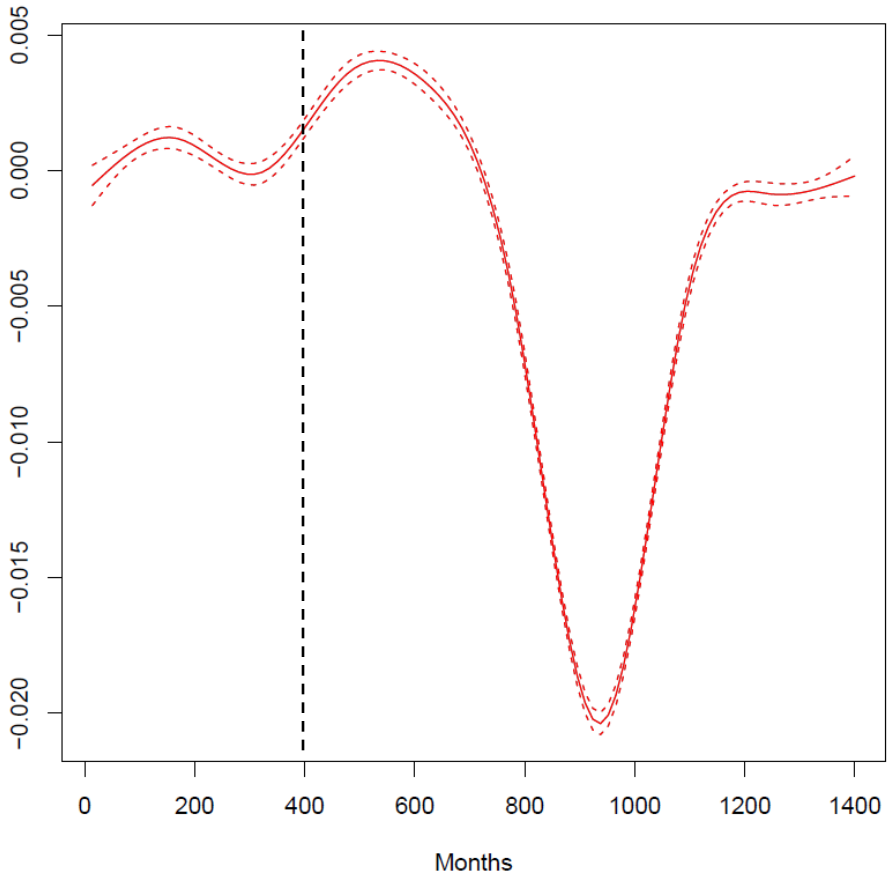
Region 2

5. Policy Analysis

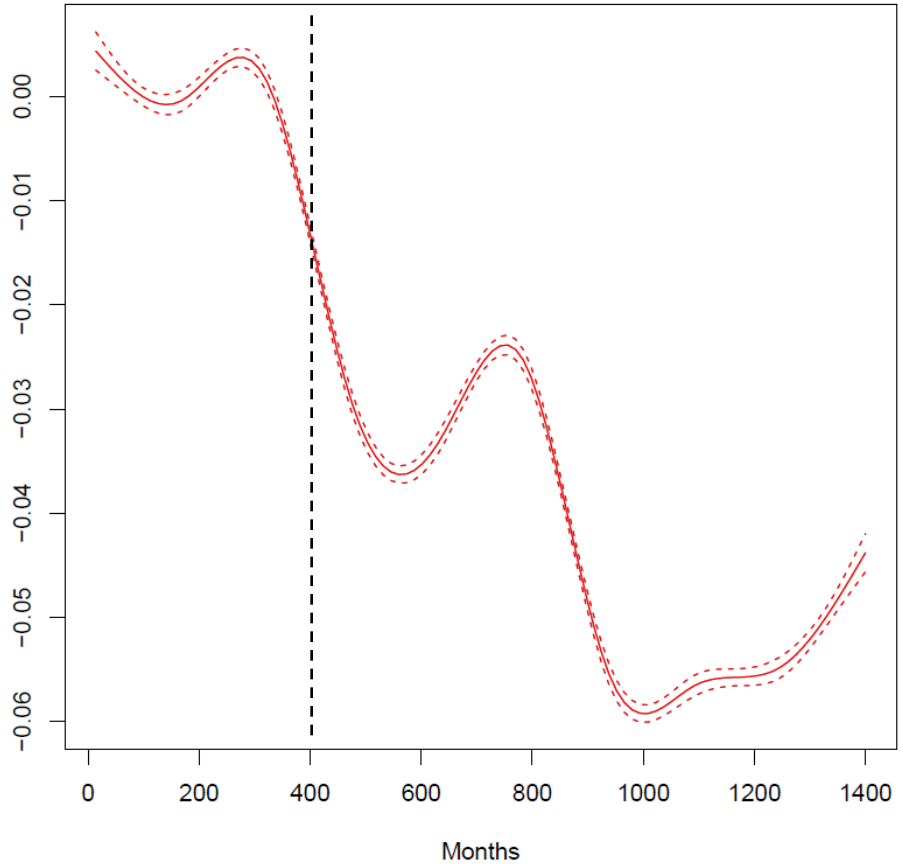
Explaining the underlying Mechanisms: Why do non-directed policies fail to foster convergence?

Effect of non-directed policy (α=0) under inflex LM on the ratio (R1/R2) of

consumption good price



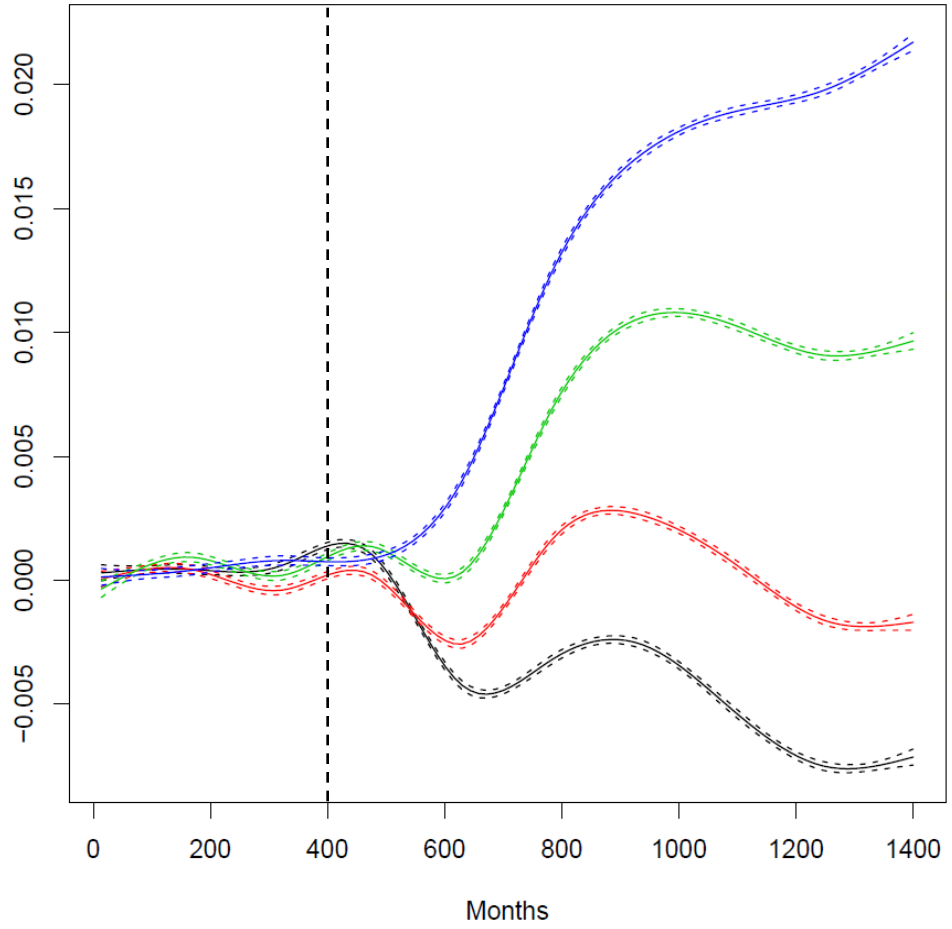
base wage offer



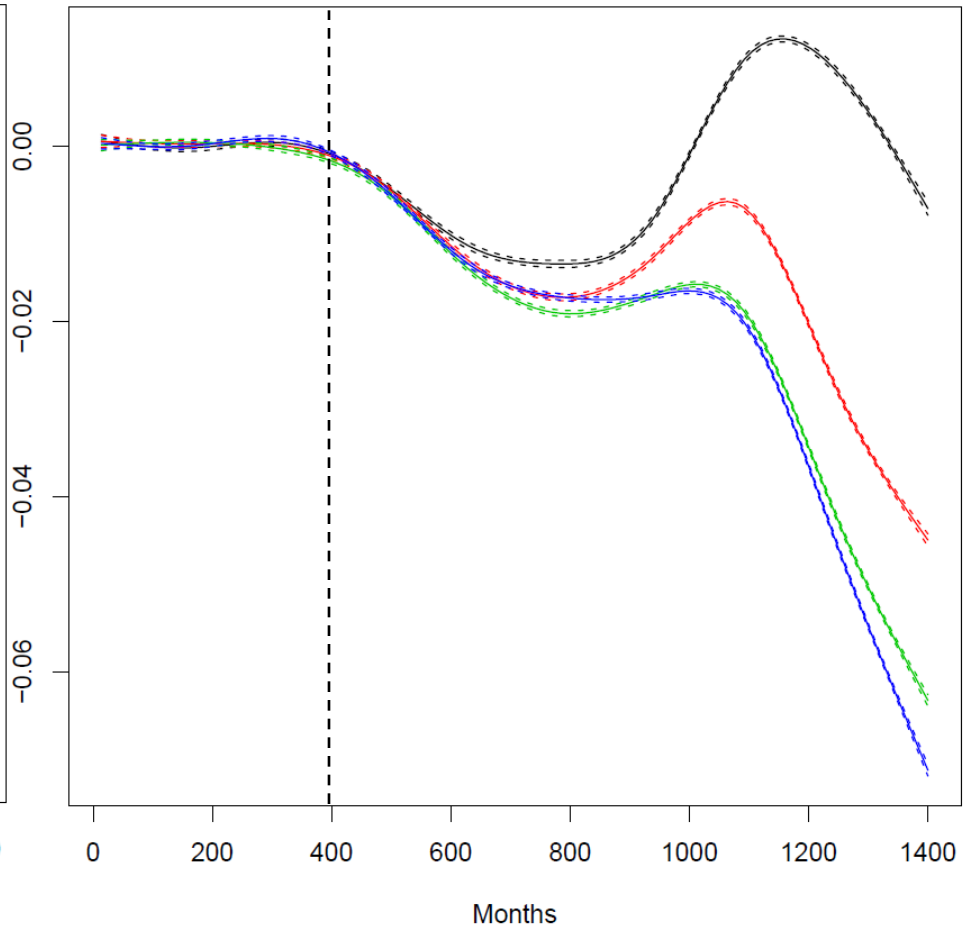
5. Policy Analysis

Gini (sep. & inflex LM)

(black: α=0, red: α=0.1, green: α=0.2, blue: α=0.3)



Region 1



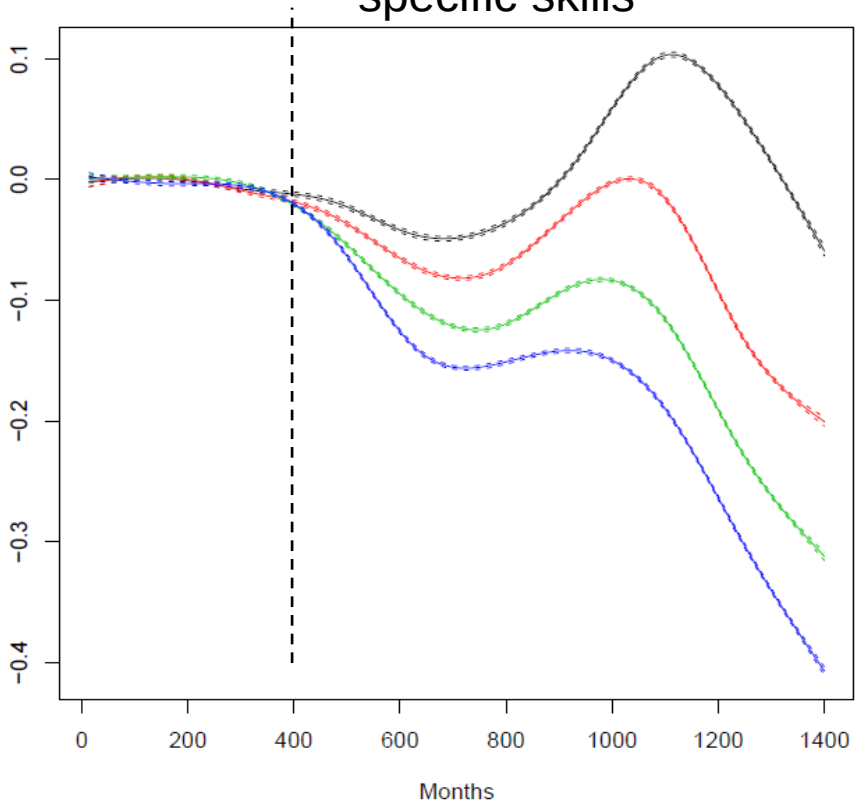
Region 2

5. Policy Analysis

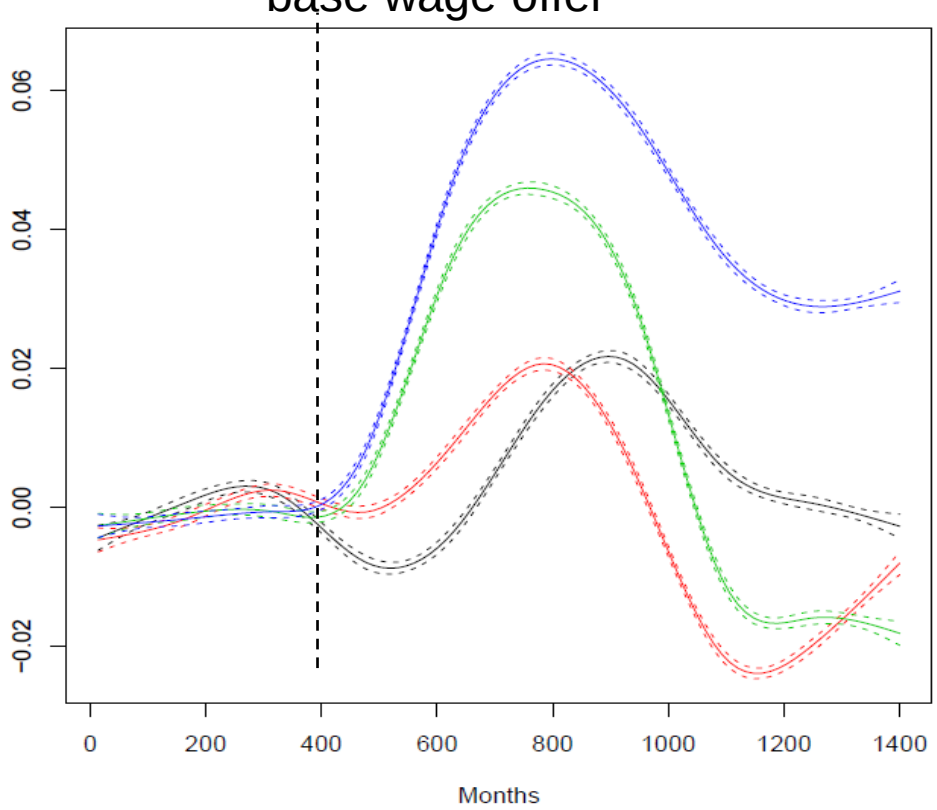
Explaining the underlying Mechanisms: Why do targeted policies lead to a reduction of inequality in R2?

Effect of all tech-policies on the ratio (high-prod./low-prod. firms) of average values of

specific skills



base wage offer



(black: α=0, red: α=0.1, green: α=0.2, blue: α=0.3)

6. Fostering Transparency, Reproducibility & Replication

- For newcomers to agent-based modeling entry costs are often very high:
  - developing own models from scratch is time consuming and requires strong programming skills
  - for existing models the code is often not available or not sufficiently documented such that it can be worked with
  - Different plattforms and Graphical Usuer Interfaces (GUI)
- For peers the effort to reproduce simulation results in published (or submitted) papers is often prohibitively high.
- Making available easy-to-use user interfaces for existing (large) ABMs in economics therefore is important to foster the diffusion of this modeling approach as well as reproducibility and replicability.

6. Fostering Transparency, Reproducibility & Replication

ETACE Virtual Appliance

- The ETACE Virtual Appliance is a stand-alone Linux-based simulation platform that provides a full suite of programs for agent-based modeling and simulation (currently including only different versions of the Eurace@Unibi model).
- The virtual appliance serves multiple purposes:
  - to ensure the reproducibility of results,
  - as a form of model documentation and communication,
  - it reduces costs of using the model and increases the credibility of the model.
- Platform independent; only requirement is a virtual machine client (e.g. Oracle VM VirtualBox)

6. Fostering Transparency, Reproducibility & Replication

ETACE Virtual Appliance

- The ETACE Virtual Appliance includes the implementations of the models underlying different (published) research papers as well as pre-configured scripts launching experiments carried out in the papers.
- Allows to exactly reproduce experiments reported in the paper.
- Allows designing and running alternative experiments testing the robustness of the reported results.

-> ETACE VA Demo

Thank you for your attention!

Information about Eurace@Unibi
and an extensive model documentation at:

http://www.wiwi.uni-bielefeld.de/lehrbereiche/vwl/etace/Eurace_Unibi/

ETACE Virtual Appliance to run the Eurace@Unibi model at:

http://www.wiwi.uni-bielefeld.de/lehrbereiche/vwl/etace/Eurace_Unibi/Virtual_Appliance

ACE Introductory Material

- Leigh Tesfatsions ACE webpage:

http://www2.econ.iastate.edu/tesfatsi/ace.htm

- List of References for these slides is provided in a separate file.

- Collection of Surveys on ACE topics:
  - L. Tesfatsion and K. Judd (Eds.): Handbook of Computational Economics, Volume II, North-Holland, 2006.
  - S.-H. Chen and M. Kaboudan (Eds): Handbook on Computational Economics and Finance.; Oxford University Press, 2018 (forthcoming).
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