Modeling the Economy as a Complex System

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Overview

- Complexity and Economic Modeling
- Agent-based Approach to Economic Modeling
- Examples of Agent-Based Analyses
  - Models of Specific Markets
  - Macroeconomic Policy Models
- Conclusions & Outlook
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:
  - Agents of the same type are identical (‘representative agent’) or vary only with respect to a single parameter
  - 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
  - Difficulties in matching basic empirical stylized facts: exogenous shocks or model inconsistent ad-hoc additions (Calvo pricing, rule-of-thumb consumers) are often needed
  - Emerging properties typically cannot be captured
  - Little can be said about distributional issues
  - 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
Useful Approach for Policy Analysis?

- Short and medium run effects of policies are as relevant as the long run.
- Policy effects are often most relevant in situations far off the long run equilibrium, e.g. in crises.
- Effects of policies on individual behavior might be a bad predictor for policy implications on the aggregate level.
- Policy effects can be crucially affected by temporary imbalances, potential lock-ins and path-dependencies.
- Capturing institutional setup (market rules etc.) is often key.
- Normative policy analysis should capture boundedly rational reactions of economic agents.
Analytical Considerations

- Dynamics of ABMs typically correspond to ergodic Markov chains with very large state space and complex transitions probabilities

- Only very general insights about dynamic properties using Markov theory (e.g. Dawid (1999))

- Recent work on analytical characterization of the (approximate) dynamics of distribution moments in very simple agent-based model using a statistical physics techniques (e.g. Alfarano et al. (2008), Delli Gatti et al. (2012))

-> dynamic properties typically explored by simulation
Key Issues and Challenges for AB Modeling in Economics

- Markets and Economic Transactions
- Individual Agent Behavior and Learning
- Parametrization, Calibration and Fit to Empirical Data
- Policy Analysis and Market Design using ACE models
Individual Agent Behavior and Learning

- **Individuals:**
  - Experimental Evidence (e.g. Arifovic & Ledyard (2010, 2012), Hommes (2011))
  - Decision Heursitics (e.g. Gigerenzer & Gaissmaier (2011))
  - Stakeholder Involvement (e.g. Janssen & Ostrom (2006))

- **Organizations (in particular Firms):**
  - Plausible heuristic rules (e.g. Nelson & Winter (1982), Ashraf et al. (2011))
  - Emerging decision rules matching observed behavior (e.g. Dosi et al. (1999), Midgley et al. (1997))
  - Documented heuristic firm procedures (Dawid and Reimann (2007), Dawid and Harting (2012))
Parametrization, Calibration and Fit to Empirical Data

Main challenges:
- Large number of parameters
- Path dependent and complex dynamics of simulation output
- Missing systematic concept of ‘good match with empirical data’

Main approaches:
- History-friendly-models (e.g. Malerba et al. (2001), Malerba and Orsenigo (2002))
- Indirect calibration: reproducing stylized facts (see e.g. Dosi et al. (2010), Dawid et al. (2014a))
- Estimation: first attempts (Grazzini & Richiardi (2013)), feasible for large models?
Parametrization, Calibration and Fit to Empirical Data

- 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’?
Policy Analysis and Market Design using ABMs

- Establish policy effects in a statistically clean way:
  - statistical tests on (static) aggregate indicators
  - estimating dynamic statistical models: penalized splines

\[ Y_{t,p,i} = s(t) + I_{[p(LM)=1]}s_{Flex}(t) + I_{[p(Tech)=1]}s_{Tech}(t) + I_{[p(LM)=p(Tech)=1]}s_{Int}(t) + \eta_i^0 + \eta_i^1 t + \varepsilon_{t,p,i} \]

- Gain a clear understanding of the economic mechanisms:
  - search for causal chains by considering time series of micro/meso level variables
  - establish causal relationships by systematic tools like regression trees (e.g. Vallee and Yildizoglu (2006))

- Check robustness of policy effects
Examples of Agent-Based Analyses

i) Models of particular markets and industries with rich (institutional) structure

- Electricity Markets (e.g. Li et al., 2011)
- Housing Markets (e.g. Geanakoplos et al., 2012)
- Computer Industry (Malerba et al., 1999)
- Biotech Industry (Malerba et al., 2002)
- Financial Markets (e.g. LeBaron, 2006)
- Market for Law Clerks (Haruvy et al. (2006))
- Lottery Markets (Chen and Chie (2008))
- …
Example: Housing Market
(Geanakoplos et al., 2012)

Objective:

- understanding the housing boom and crash of 1997–2009
- exploring the role of leverage vs. interest dynamics

Data-driven approach: extensive use of empirical data and distributions from Washington D.C. area

- income, wealth, age of HHs
- patterns of HH movements
- pricing behavior of sellers (adjustment dynamics of markups)
- desired payments of buyers, desired loan to value ratio (LTV)
- loan approvals according to standard rules (LTV, debt/income)
- buyers bid for highest value house they can afford
Example: Housing Market
(Geanakoplos et al., 2012)

Reproducing Stylized Facts

House Prices

Days on the Market
Example: Housing Market
(Geanakoplos et al., 2012)

Experiments: some variables are fixed deviating from historical data

Fixed Interest Rate

Fixed LTV
Examples of Agent-Based Analyses

ii) Macroeconomic models

a) Simple Model Structures with „Heterogenous Agents Parts“ and Social Dynamics

- Heterogenous expectations in dynamic equilibrium models (Arifovic et al., 2013, DeGrauwe, 2008, Anufriev et al., 2013)

- Heterogenous trust in government announcements (Arifovic et al., 2010)

- ...


Examples of Agent-Based Analyses

ii) Macro-models

b) Closed Models with full bottom-up structure

- 'Pisa Model' (Dosi et al., 2010, 2013): fiscal, monetary, competition, patent policies
- 'Ancona Model' (Delli Gati et al., 2008), Richetti et al., 2013, ...): credit linkages
- LAGOM Model (Wolf et al. '12, ...): climate policy
- Ashraf et al. ’12: Bank regulation
- Eurace@Unibi Model (Dawid et al., 2014): fiscal, innovation, labor, cohesion policies
- ...
The Eurace@Unibi Model

**Overall Objective:**
- Develop an empirically grounded agent-based model for
  - analysis of economic dynamics on different time scales
  - evaluation of policy measures in different economic domains
  - gaining an understanding of underlying mechanisms

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

GDP-Growth

Firm Size Distribution
Dynamic Properties and Stylized Facts

Beveridge Curve

Eurace@Unibi

(Ghayad & Dickens, 2012)
Behavioral Assumptions and Stylized Facts on the Micro Level

Individual Firm Output in Eurace@Unibi

endog. mark-up

const. mark-up
Stylized Facts

Model generates output which qualitatively matches numerous empirical stylized facts on different levels of aggregation (see e.g. Dawid et al. (2012)):

- Macro: business cycle properties, co-movement of key variables with business cycles, auto-corellations, relative volatilities
- Industry: firm size distribution, mark-up dynamics
- Labor market: Beveridge curve, skill-based wage dispersion
Some Key Features: 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*)

- **Wages** are firm-specific and vary across general skill groups (determined by average productivity and labor market tightness)

- Spatial labor market frictions determined by *commuting costs*
Some Key Features: Technological 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).
Policy issues addressed using the Eurace@Unibi model:

- 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, 2014)
- 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)
Policy Example: Cohesion Policy

- 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).

- 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
     - ...
Cohesion Policy in the EU

Yet, regional differences both with respect to per-capita GDP and (intra-regional) income inequality are very persistent:

- Per-capita GDP
- Gini-coefficient
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)
Policy Experiments

2 Regions: High Tech (R1) and Low Tech (R2)

2 policies:

1. 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.

   \[ \alpha \text{: fraction of firms in R2 that are induced by the policy to purchase highest vintage: } \alpha = 0.1, 0.2, 0.3 \]

2. Human Capital (HC) Policy: Upgrade general skill distribution in region 2 to that of region 1. Skill upgrading takes effect after 120 months.
Effect of Tech Policy
Output (sep. & inflex LM)
(black: $\alpha=0$, red: $\alpha=0.1$, green: $\alpha=0.2$, blue: $\alpha=0.3$)
Explaining the underlying Mechanisms: Why do non-targeted policies fail to foster convergence?

Effect of non-targeted policy ($\alpha=0$) under inflex LM on the ratio ($R1/R2$) of consumption good price and base wage offer.
Effect of Tech Policy

Gini (sep. & inflex LM)

(black: $\alpha=0$, red: $\alpha=0.1$, green: $\alpha=0.2$, blue: $\alpha=0.3$)
Effect of higher LM Flexibility in R2 on Policy Effect
Output (sep. & inflex LM)
(black: $\alpha=0$, red: $\alpha=0.1$, green: $\alpha=0.2$, blue: $\alpha=0.3$)
Overall..

- ABMs are complementing existing policy models
  - DSGE, End. GT, Econometric Models,..

- In particular specific market models have been calibrated to match closely empirical data on micro and meso level (can in principle be used for generating also quantitative predictions).

- Existing economic ABMs mainly used as theorizing devices addressing issues and highlighting relevant channels of policy effects not captured in alternative approaches!
High-Potential Areas for Agent-Based Models

- Distributional issues, generation and evolution of inequality
- Integrating social networks, opinion formation, information transmission in economic models
- Emphasizing spatial structure
- Market design, institutional design
- Linking macro and finance, macro and labor
- Linking ABMs to simulation models from other areas
  - Climate
  - Demography
  - …
On the Agenda

- Linking distributional model predictions to data
- Explicit consideration of (heterogeneous) expectation formation processes
- Unified systematic approaches for determination of behavioral rules of agents
- Systematic approaches to model validation and cross model comparison
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
Papers based on the Eurace@Unibi model


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