Economic Forecasting with an Agent-Based Model

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Outline of presentation

1. Introduction: research questions and overarching ideas.
2. Short introduction into agent-based models (ABMs).
3. Short critique of ABM literature.
4. Development of novel estimated ABM **framework** validated by economic forecasting:
   - "Economic forecasting with an agent-based model", [Poledna et al., 2019].
5. Conclusion and future research.

Model development

"Economic forecasting with an agent-based model" [Poledna et al., 2019] is joint work with with Sebastian Poledna, who is the main developer of the ABM, and Cars Hommes.

The development of the ABM was primarily financed and carried out at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg.

Research questions

- Q1: How can agent-based models (ABMs) be **empirically estimated** in a solid way?
- Q2: How can ABMs be **empirically validated** comprehensively, and how can they be **made comparable** to standard methods of economic analysis?
- Q3: Is it possible to make ABMs viable to conduct **economic forecasts** and **simulation experiments** for "actual" economies?

Overarching ideas and research agenda

- Use **Data from national accounts** to *estimate* ABM to a national economy (Austria).
- Keep ABM simple – **no free parameters**.
- Use **Parameter-free adaptive learning** for expectation formation.
- Construct an ABM without an initial transient (**burn-in**) phase.
- Validation: Compare **forecasting performance** of ABM to that of standard models, e.g. (simple) times series models and a standard DSGE model.

Outlook: Can the construction of this type of empirically estimated ABMs be a way to **address the Lucas critique** from a new angle, i.e.

- Incorporate detailed *micro-foundations*, *forward looking behaviour* + *endogenous model dynamics* of economy as a complex system (emergence),
- Compensating for potential weaknesses of more standard approaches such as DSGE models, and satisfying the Lucas critique at the same time?

Agent-based models

ABMs – **computer simulation models**:

- **Individual agents** and individual decisions (decentralized decision making).
- **Emergent patterns** from micro-processes aggregate to a macro level:
- The economy as a **complex system** subject to **fundamental uncertainty**:
  - E.g. Gross Domestic Product (GDP) as a macroeconomic aggregate is calculated from the market value of all final goods and services produced by individual agents, where the market value emerges from trading in the ABM.
- Markets are depicted from the "bottom-up" by **search & matching** procedures.
- **Local interaction networks** between agents - **parallel computing**.
- Explicit **micro-foundations** - **large data sets** can be included.
- Quantity and quality of **big data** is expanding rapidly (data sets with near-universal population coverage; real-time data flows).
- Steadily rising computing power (**supercomputers**).

Construction of **large economic models** that incorporate **low level details** possible.

Critique of ABM Literature

Current ABMs - **impediments** for calibration/estimation, and replication of "actual" economies on empirical basis:

- **Over-parameterization**,
- Absence of solid **empirical calibration, estimation, and validation** procedures,
  - replication of "stylized facts" only a weak test for validity of a model,
- Ad hoc and **arbitrary** choices on agents' behaviour and characteristics,
- Too many **degrees of freedom**?
- Existence of transient (**burn-in**) phase.
- Lack of **comparability and reproducibility**,
- **"Black boxes"**.

"**Wilderness of bounded rationality**" [Sims, 1980].

Economic forecasting: ABM for a small open economy

An empirical ABM that depicts the national economy of Austria.

- Incorporates **all economic activities** (producing and distributive transactions) as classified by the European system of accounts (ESA).
- Includes **all economic entities**: all juridical and natural persons are represented by agents.
- Integrates data from input-output tables (IOTs), national annual sector accounts (NASA), government statistics, census and business demography data, and business surveys.
- Behavioural equations used are standard in literature, e.g. [Delli Gatti et al., 2011, Assenza et al., 2015]
- Parameters are estimated rather than calibrated, no free parameters,
  - $\rightarrow$ No "burn-in" phase.
- **Empirical validation:** compare out-of-sample prediction performance of the ABM with that of autoregressive (AR), vector autoregressive (VAR) and DSGE models estimated on the same observable time series.

Agents & markets

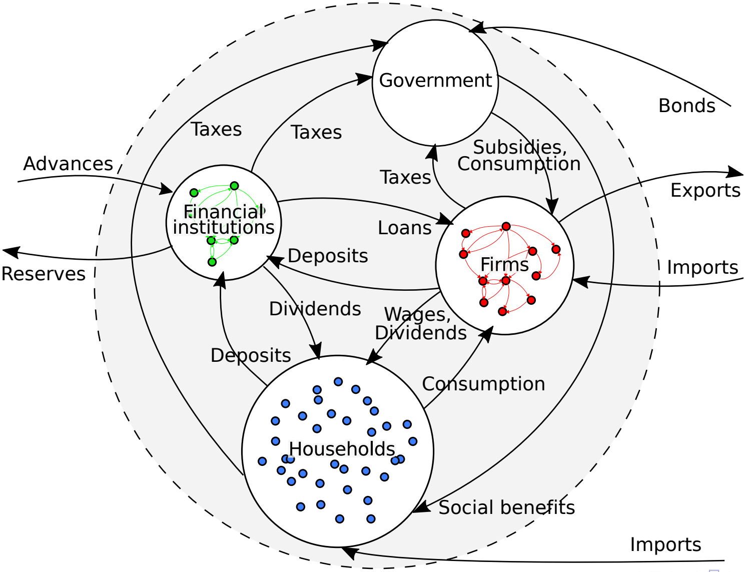
Agents:

- Non-financial corporations (firm sector), limited companies and self-employed – ca. 600 000 firm agents.
- Financial corporations (banking sector), one representative bank.
- Households (individual persons) - ca. 8.2 million household agents:
  - Employed (active on labor market),
  - Unemployed (involuntarily idle),
  - Investor (own firms),
  - Inactive households (not active on labor market, receive social benefits).
- General government.

Markets: characterized by *search & matching*

- 64 different products according to sectoral structure as in IOT,
- These products can be used for consumption, or for investment/intermediate inputs (different markets),
- Additional markets: labour, credit and deposits.

Major Economic Agents and their Interactions



Agent behavior

- Each **firm** chooses its supply, prices, production and investment:
  - Supply Choice according to expected demand (expected real economic growth),
  - Pricing according to expected costs (expected inflation),
  - Production by limitational (Leontief) production technology,
  - Investment accounting for expected wear and tear of capital.
  - Realized sales: minimum of supply choice, demand, and production possibilities (*search & matching*).
- Each **household** expects nominal disposable income $Y_h^e(t)$ depending on the *activity status* and expected inflation.
  - spends a (fixed) fraction of this expected income on **consumption** and **investment**.
- The general government mainly acts as a consumer **(government consumption)** and as a **'redistributional' entity**.
- The **banking sector** takes deposits from firms and households, extends loans to firms, and receives advances from or deposits reserves at the central bank.
- **Interest rates** $r(t)$ are determined by means of a fixed risk premium μ over the policy rate $\bar{r}(t)$ set by the central bank according to a Taylor rule.

Expectations – parameter-free adaptive learning

Parameter-free adaptive learning: Agents (firms and households) act as econometricians who estimate the parameters of their model to make forecasts of key macroeconomic aggregates.

Expectations: formed according to an autoregressive model of lag order one (**AR(1)**).

AR models: Dependent variable $x(t)$ explained by its lag(s) up to order p, and an error term $\epsilon(t)$.

The expected real growth rate $\gamma^e(t)$ and the expected inflation rate $\pi^e(t)$ are inferred from agents' predictions of (expected) gross domestic product (real GDP, in log levels) and inflation (the GDP deflator *DEFL*, 2010=100), lag order one:

$$GDP^e(t) = \alpha^{GDP} GDP(t-1) + \epsilon^{GDP}(t) \quad (1)$$

$$DEFL^e(t) = \alpha^{DEFL} DEFL(t-1) + \epsilon^{\pi}(t) \quad (2)$$

For both expectation formation and forecasting below, we used the AIC and BIC criterion to determine the optimal lag length for the AR model.

Firms: Supply Choice & Pricing (Adaptive Learning)

Supply choice/demand expectations:

Firms forms expectations about economic growth ($\gamma^e(t)$) according to AR(1) process, i.e. by **parameter-free adaptive learning**. Each firm i adapts desired scale of activity ($Q_i^s(t)$) according to the previous period's demand ($Q_i^d(t-1)$) and the assumptions about the development of the real growth rate ($\gamma^e(t)$)

$$Q_i^s(t) = Q_i^e(t) = Q_i^d(t-1)(1+\gamma^e(t)) \tag{3}$$

Pricing: according to expected inflation rate $\pi^e(t)$, cost-structure ('cost-push inflation'), unit target operating surplus:

$$P_i(t) = \overbrace{\frac{w_i(t)(1+\tau^{SIF})\bar{P}^{HH}(t-1)(1+\pi^e(t))}{\alpha_i(t)}}^{\text{Unit labour costs}} + \overbrace{\frac{1}{\beta_i}\sum_g a_{sg}\bar{P}_g(t-1)(1+\pi^e(t))}^{\text{Unit Material costs}} + \overbrace{\frac{\delta_i}{\kappa_i}\bar{P}^{CF}(t-1)(1+\pi^e(t))}^{\text{Unit capital costs}}$$
$$+ \underbrace{\tau_i^Y P_i(t-1)(1+\pi^e(t))}_{\text{Unit net taxes/subsidies products}} + \underbrace{\frac{\tau_i^K}{\kappa_i\omega}\bar{P}^{CF}(t-1)(1+\pi^e(t))}_{\text{Unit net taxes/subsidies production}} + \underbrace{\bar{\pi}_i P_i(t-1)(1+\pi^e(t))}_{\text{Target unit operating surplus}} \tag{4}$$

Firms: Output & Investment

Output $Y_i(t)$ produced via:
(1) intermediate inputs $M_i(t)$, (2) labor $N_i(t)$, (3) capital stock $K_i(t-1)$,
with a fixed coefficient (Leontief) technology, where the coefficients are obtained from IOTs:

$\alpha_i(t)$, β_i and κ_i – productivity coefficients,
a_{sg} – technologically determined input ("technology") coefficients:

$$Y_i(t) = \min\left(Q_i^s(t), \frac{\beta_i}{a_{s1}} M_{i1}(t-1), \frac{\beta_i}{a_{s2}} M_{i2}(t-1), \ldots, \frac{\beta_i}{a_{sg}} M_{ig}(t-1), \alpha_i(t) N_i(t), \kappa_i K_i(t-1)\right) \quad (5)$$

Investment – according to:
(1) depreciation rate of capital δ_i, (2) productivity of capital κ_i, and (3) desired scale of activity $Q_i^s(t)$ based on demand expectations,

$$I_i^d(t) = \frac{\delta_i}{\kappa_i} Q_i^s(t) = \frac{\delta_i}{\kappa_i} Q_i^e(t) = \frac{\delta_i}{\kappa_i} Q_i^d(t-1)[1 + \gamma^e(t)] \quad , \quad (6)$$

Non-financial and Financial Corporations (Firms): Economic activities

- Output (P.1)[1] $\rightarrow$ part of which results in realized sales:
- + $P_i Q_i$ where P_i is price charged, and Q_i are realized sales of firm i
- - Intermediate consumption (P.2)
- - Capital consumption (P.51C)
- - Wages and salaries (D.11)
- - Employers' social contributions (D.611)
- - Taxes on products (D.21)
- - Other taxes on production (D.29)
- + Subsidies on products (D.31)
- + Other subsidies on production (D.39)
- = Operating surplus (B.2A3N)
- - Interest (D.41)
- - Taxes on income (D.51)
- - dividend payments (D.42)

[1] The ESA code is given in brackets.

Households - income: each household forms expectations on its expected nominal disposable income $Y_h^e(t)$ (i.e. expected net income after taxes and including social or unemployment benefits):

$$Y_h^e(t) = \begin{cases} \left(w_h(t)\left[1-\tau^{SIW}-\tau^{INC}(1-\tau^{SIW})\right]+sb^{other}\right)\bar{P}^{HH}(t-1)(1+\pi^e(t)) & \text{if employed} \\ \left(w_h(t)+sb^{other}\right)\bar{P}^{HH}(t-1)(1+\pi^e(t)) & \text{if unemployed} \\ \left(sb^{inact}+sb^{other}\right)\bar{P}^{HH}(t-1)(1+\pi^e(t)) & \text{if not economically active} \\ \theta^{DIV}(1-\tau^{INC})(1-\tau^{FIRM})\max(0,\Pi_i^e(t))+sb^{other}\bar{P}^{HH}(t-1)(1+\pi^e(t)) & \text{if an investor} \\ \theta^{DIV}(1-\tau^{INC})(1-\tau^{FIRM})\max(0,\Pi_k^e(t))+sb^{other}\bar{P}^{HH}(t-1)(1+\pi^e(t)) & \text{if a bank investor} \end{cases} \tag{7}$$

Here,

$w_h(t)$ is wage income or unemployment benefits (which are a fixed fraction θ of the wage last earned before the unemployment) of household h,

$\bar{P}^{HH}(t-1)$ is last period's consumer price index,

$\Pi_i^e(t)$ are expected profits of firm i, $\Pi_k^e(t)$ are expected bank profits,

sb^{inact} are social benefits for inactive persons (mostly pension payments), sb^{other} social benefits distributed equally to all households

τ^{INC} is the income tax rate, τ^{SIW} is the rate of social insurance contributions to be paid by the employee, θ^{DIV} is the dividend payout ratio, and τ^{FIRM} the corporate tax rate.

Households: Consumption, Investment & Savings

Households spend a fraction of their expected income on **consumption:**

$$C_h^d(t) = \frac{\psi Y_h^e(t)}{1+\tau^{VAT}} \tag{8}$$

and on **investment:**

$$I_h^d(t) = \frac{\psi^H Y_h^e(t)}{1+\tau^{CF}}, \tag{9}$$

where ψ, ψ^H are propensities to consume,invest out of expected income; τ^{VAT}, τ^{CF} are value added, investment tax rates. Total household consumption allocated to goods g according to fixed coefficients from IOTs, analogous to firm investment above.

Households' consumption, investment plans need not be realized (fundamental uncertainty!): expectation mistakes, search and matching

Savings: difference between realized disposable income $Y_h(t)$, realized consumption expenditure $C_h(t)$, used to accumulate financial wealth:

$$D_h(t) = D_h(t-1) + \overbrace{Y_h(t) - [(1+\tau^{VAT})C_h(t) + (1+\tau^{CF})I_h(t)]}^{\text{Savings}} \tag{10}$$

Households: Economic activities

- + Wages and salaries (D.11)
- + Property Income (D.4)
- + Mixed Income from Self-Employment (B2A3N)
- + Social benefits other than social transfers in kind (D.62)
- + Other current transfers net (D7, D8, D.9)
- - Final consumption expenditure (P.3)
- - Taxes on products (D.21)
- - Taxes on income (D.5)
- - Employees' social contributions (D.612, D.613, D.614)
- - Capital formation (dwellings) (P.51)

General Government: Economic activities

Government mainly acts as a consumer **(government consumption)** and as a **'redistributional' entity**: consumes on the goods market to provide a public good, collects taxes, provides transfers.

- + Taxes on income (D.5, D.91)
- + Taxes on products and production (D.2)
- + Property Income (D.4)
- + Social contributions (D.61)
- - Final consumption (P.3)
- - Subsidies (D.3)
- - Interest payments (D.41)
- - Social benefits other than social transfers in kind (D.62)
- - Other current expenditures (D.7, D.8, D.9)

Exports, Imports, Government Consumption

According to the **small open economy (SoE)** assumption as appropriate for the Austrian economy and exogenous policy decisions, these economic aggregates are either assumed to be

- exogenously given from data (conditional forecasts),
- or to follow autoregressive (AR) processes according to the SoE setting for Austria

Thus, imports $Y^I(t)$, exports $C^E(t)$ and government consumption $C^G(t)$ (all real and in log levels) either follow AR(1) processes (unconditional forecasting setup):

$$Y^I(t) = \alpha^I Y^I(t-1) + \epsilon^I \quad (11)$$

$$C^E(t) = \alpha^E C^E(t-1) + \epsilon^E \quad (12)$$

$$C^G(t) = \alpha^G C^G(t-1) + \epsilon^G, \quad (13)$$

or are given exogenously in the conditional forecasting setup.

Parameter setting: European System of Accounts

- Input-output tables (IOTs)
- National annual sector accounts (NASA)
- Government statistics
- Demographic statistics and census data
- Business surveys

Table: National Accounting Data: EUROSTAT Data Tables Used

GDP and main components - output, expenditure and income (quarterly)
Symmetric input-output table at basic prices (product by product)
Cross-classification of fixed assets by industry/asset (stocks)
Balance sheets for non-financial assets
Non-financial transactions
Business demography by legal form
Current level of capacity utilization in manufacturing industry
Government revenue, expenditure and main aggregates
Government deficit/surplus, debt and associated data
Government expenditure by function
Population by current activity status

Table: Unconditional forecasting performance

	GDP growth	GDP deflator growth	Household consumption	Investment	Euribor
AR(1)	*RMSE-statistic for different forecast horizons*				
1q	0.62	0.37	0.66	1.4	0.05
2q	0.89	0.36	0.93	2.21	0.1
4q	1.33	0.34	1.32	3.5	0.16
8q	1.48	0.37	1.57	4.34	0.21
12q	1.31	0.33	2	6.09	0.26
ABM	*Percentage gains (+) or losses (-) relative to AR(1) model*				
1q	-1.7 (0.02)	0 (0.96)	0.5 (0.94)	8.9 (0.13)	-235.7 (0.00)
2q	-1.8 (0.30)	-1.2 (0.29)	0.5 (0.96)	10.2 (0.20)	-90.3 (0.19)
4q	0.2 (0.93)	1.1 (0.14)	7.1 (0.62)	9.2 (0.28)	-15.9 (0.78)
8q	5.9 (0.13)	0.4 (0.78)	21.6 (0.04)	29.8 (0.00)	58 (0.00)
12q	4.6 (0.54)	-0.3 (0.10)	29.8 (0.00)	39.6 (0.00)	79.6 (0.00)
DSGE	*Percentage gains (+) or losses (-) relative to AR(1) model*				
1q	-5.7 (0.62)	5.3 (0.59)	7.9 (0.31)	22.1 (0.24)	-16 (0.06)
2q	-3.4 (0.80)	-20 (0.17)	7.2 (0.43)	31.4 (0.28)	-39.1 (0.01)
4q	15.1 (0.17)	-8.2 (0.00)	25.3 (0.13)	37.9 (0.26)	-70.2 (0.00)
8q	39 (0.08)	1.7 (0.43)	10.9 (0.32)	36.1 (0.16)	-132.2 (0.00)
12q	28.5 (0.00)	-4.3 (0.63)	7.1 (0.37)	50.8 (0.00)	-139.2 (0.00)

Table: RMSE-statistic for different forecast horizons from 2010:Q2-2016:Q4 of ABM in comparison to AR(1) and DSGE models (**unconditional forecasts**). Values in brackets indicate p-values of the [Diebold and Mariano, 1995] test on predictive accuracy.

Table: Conditional forecasting (exogenous predictors)

	GDP growth	GDP deflator growth	Household consumption	Investment
ARX(1)	*RMSE-statistic for different forecast horizons*			
1q	0.34	0.38	0.58	1.11
2q	0.37	0.34	0.75	1.49
4q	0.41	0.35	0.96	1.25
8q	0.53	0.35	1.22	1.07
12q	0.58	0.41	1.43	1.35
"ABMX" (cond. fc.)	*Percentage gains (+) or losses (-) relative to ARX(1) model*			
1q	3.3 (0.12)	-0.9 (0.21)	-22.1 (0.19)	-1.8 (0.94)
2q	-0.9 (0.90)	-1.1 (0.34)	-8.4 (0.62)	-11.8 (0.74)
4q	-23.1 (0.51)	0.8 (0.51)	-12.8 (0.55)	-107.1 (0.10)
8q	-1 (0.94)	-1 (0.00)	18.8 (0.05)	-142.3 (0.03)
12q	18.5 (0.00)	-1.6 (0.00)	6.6 (0.33)	-120.5 (0.06)
"DSGEX" (cond. fc.)	*Percentage gains (+) or losses (-) relative to ARX(1) model*			
1q	-60.7 (0.05)	1.4 (0.91)	-200.3 (0.08)	-1.1 (0.96)
2q	-105.8 (0.00)	-17.1 (0.28)	-196.7 (0.09)	-3.5 (0.90)
4q	-105.4 (0.00)	-12.4 (0.59)	-242.2 (0.12)	-86.2 (0.00)
8q	-144.4 (0.12)	-7.7 (0.56)	-287.6 (0.00)	-117.5 (0.00)
12q	-160.2 (0.00)	-33.9 (0.00)	-354 (0.00)	-71.9 (0.00)

Table: RMSE-statistic for different forecast horizons from 2010:Q2-2016:Q4 of ABM with 6 predictors in comparison to ARX(1) with the same predictors, as well as to a DSGE model with **conditional forecasts**. Values in brackets indicate p-values of the [Diebold and Mariano, 1995] test on predictive accuracy.

Out-of-sample Prediction Performance, Growth: 2010:Q4 - 2013:Q4

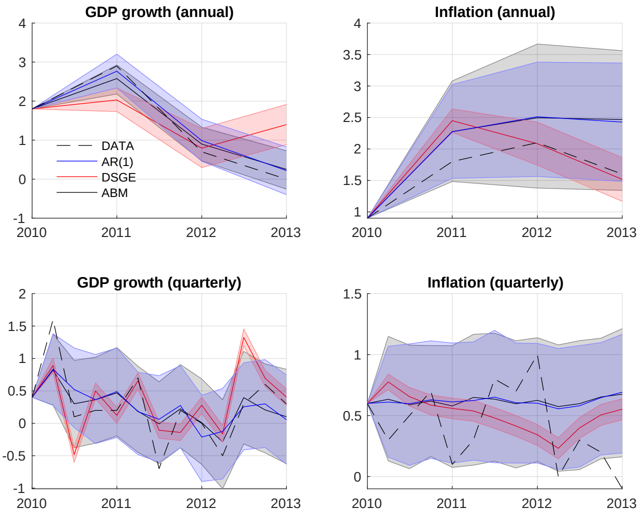


Figure: ABM (black), AR(1) (blue), DSGE (red), Eurostat data (dashed); horizon 12q

Out-of-sample Prediction Performance, Quarterly levels: 2010:Q4 - 2013:Q4

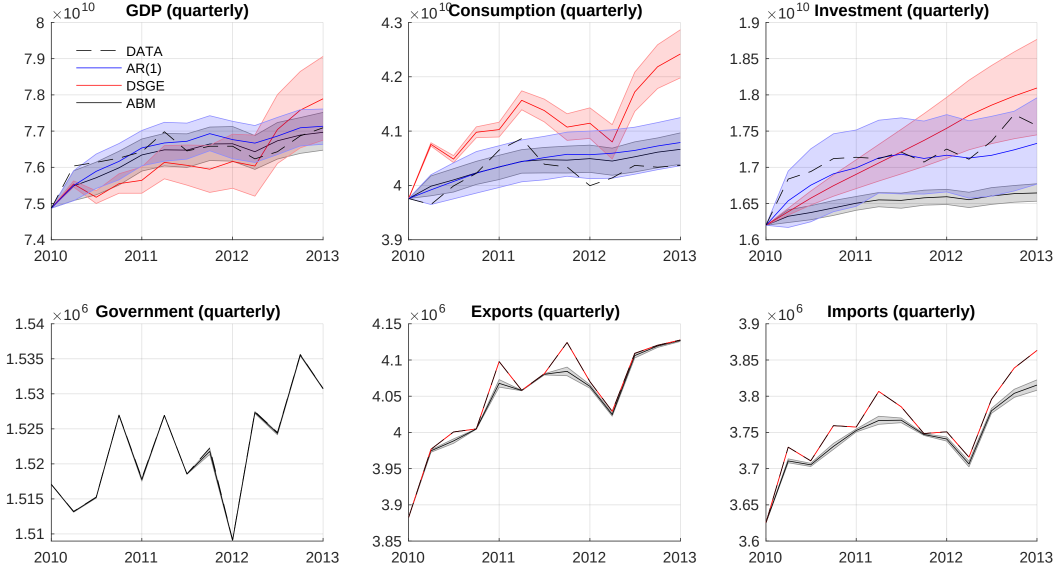


Figure: ABM (black), AR(1) (blue), DSGE (red), Eurostat data (dashed); horizon 12q

National accounting

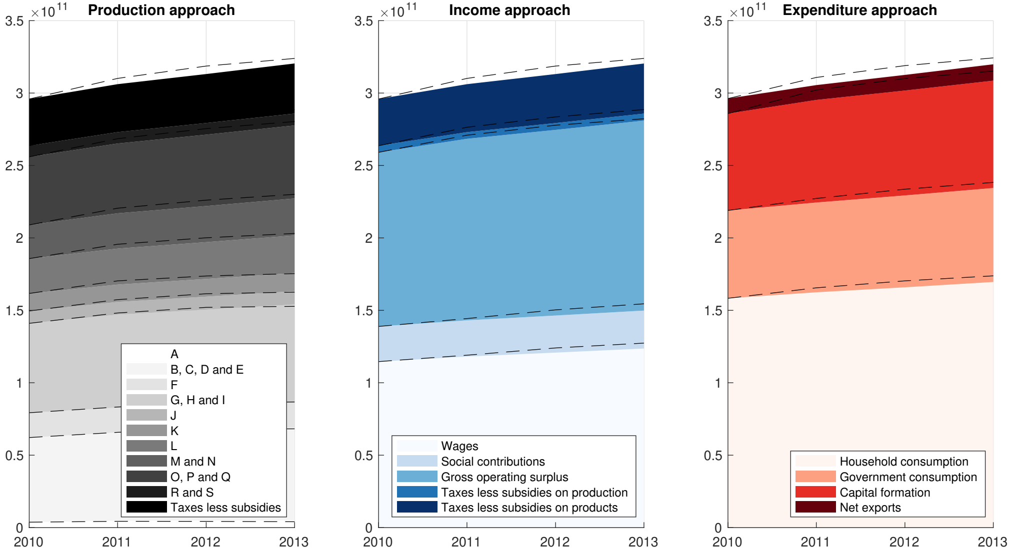


Figure: GDP: production, income, and expenditure approaches, ABM (solid) vs. data (dashed)

Figure: Sectoral decomposition: ABM simulations (solid), observed data (dashed)

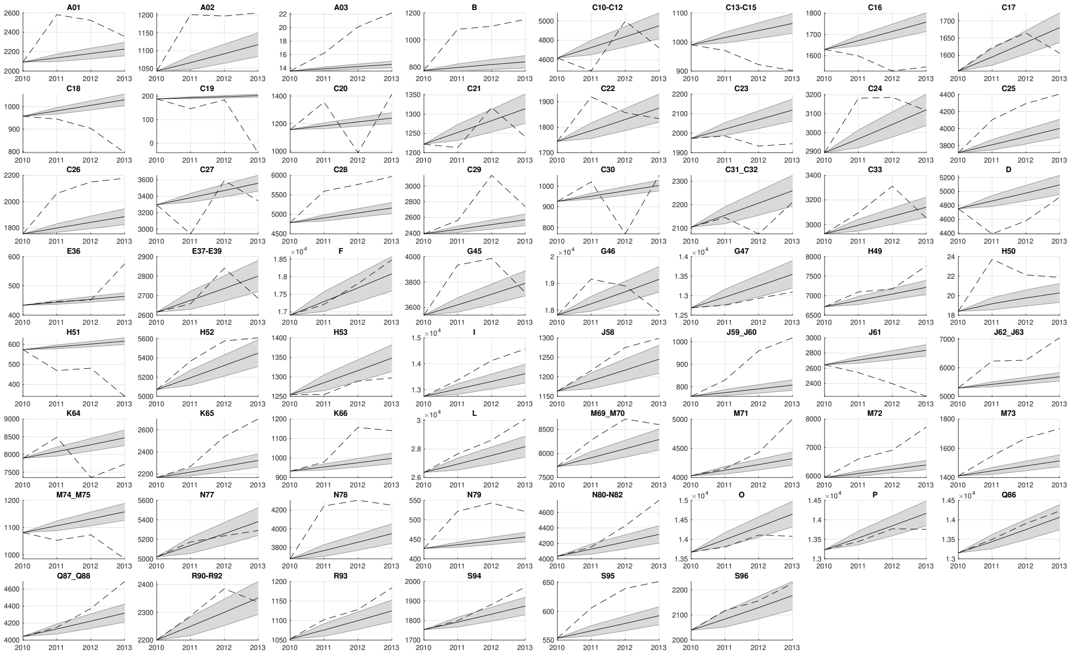


Table: Out-of-sample forecast performance of sectoral gross value added (GVA)

	A	B, C, D and E	F	G, H and I	J	K	L	M and N	O, P and Q	R and S
AR(1)	*RMSE-statistic for different forecast horizons*									
1q	10.97	1.29	1.39	0.98	2.37	3.95	0.37	1.68	0.55	0.34
2q	14.29	1.75	1.81	1.48	2.93	4.94	0.61	1.94	0.71	0.58
4q	14.13	2.62	2.74	2.46	4.77	6.79	1	2.28	1.01	0.99
8q	12.95	3.46	4.33	3.69	7.03	8.12	1.45	2.81	1.63	1.75
12q	9.6	3.5	6.62	3.47	10.01	11.57	1.98	2.77	2.06	2.63
ABM	*Percentage gains (+) or losses (-) relative to AR(1) model*									
1q	0 (1.00)	4.5 (0.41)	5.2 (0.55)	-6.9 (0.15)	4.4 (0.17)	0.8 (0.92)	-65.8 (0.00)	-6 (0.52)	10 (0.31)	-1.5 (0.92)
2q	-5.6 (0.65)	12.7 (0.22)	15.8 (0.11)	-3.9 (0.67)	13 (0.06)	2 (0.90)	-95.5 (0.00)	-16.2 (0.30)	20.7 (0.12)	6.9 (0.83)
4q	-10.2 (0.44)	19.8 (0.26)	34.5 (0.00)	2.2 (0.88)	17.9 (0.00)	14.2 (0.52)	-132.2 (0.00)	-40.1 (0.23)	29.8 (0.20)	19.2 (0.60)
8q	-10.5 (0.76)	31.3 (0.24)	64.7 (0.00)	13.9 (0.13)	32.2 (0.00)	41.9 (0.09)	-194.2 (0.00)	-68.3 (0.02)	3.9 (0.92)	25.5 (0.45)
12q	-79.3 (0.00)	41.8 (0.07)	65.7 (0.00)	26.2 (0.00)	37.5 (0.00)	53.7 (0.00)	-215.4 (0.00)	-116.3 (0.00)	-20.9 (0.59)	42 (0.00)

Sectors shown: Forestry and fishing (A); Industry (except construction) (B, C, D and E); Manufacturing (C); Construction (F); Wholesale and retail trade, transport, accommodation and food service activities (G, H and I); Information and communication (J); Financial and insurance activities (K); Real estate activities (L); Professional, scientific and technical activities, as well as administrative and support service activities (M and N); Public administration, defence, education, human health and social work activities (O, P and Q); Arts, entertainment, and recreation, as well as other service activities (R and S). The forecast period is 2010:Q2 to 2016:Q4. All models are re-estimated each quarter. ABM results are obtained as an average over 500 Monte Carlo simulations. The values in brackets indicate the *p*-values of [Diebold and Mariano, 1995] tests.

Conclusions and Contributions to the Literature

Q1: How can ABMs be **empirically estimated** in a solid way?

Answer: Development of a large-scale empirical ABM that **is estimated rather than calibrated**, **avoids burn-in phase** → first ABM comprehensively estimated to a national economy (Austria).

Q2: How can ABMs be **empirically validated** comprehensively, and how can they be **made comparable** to standard methods of economic analysis?

Answer: This ABM is able to **compete** with vector autoregressive (VAR), autoregressive (AR) and DSGE models in **out-of-sample prediction**.

Q3: Is it possible to make ABMs usable for **economic forecasts** and **simulation experiments** for “actual” economies (economic and other shocks, policy changes, etc.)?

Answer: **Applications** – *economic forecasting* and *indirect economic effects from natural disasters* for the Austrian national economy.

Outlook and future research

"Renewal" of structural macro-econometric Keynesian models? **Confront the Lucas critique from new angle**:

- Construct large-scale empirical models that *include expectation formation* and *learning* mechanisms (adaptive but also forward-looking behaviour),
- Include sophisticated *endogenous model dynamics* (emergence) + highly detailed *micro-foundations*.

'Simulation Laboratory' for economic analysis:

- Prediction of economic trends (growth, inflation, structural change, ...) on a sectoral level. Quantify effects of policy changes for single households/firms.

Possibilities for **extension** (among many others):

1. So far: Integration of "**big data 1.0**". Potential next steps: more detailed **micro-data**, e.g.: SABINA database (firms); household surveys (EU-SILC or HFCS), or full population coverage data: Austrian social security data.
2. More detailed **financial market** (linked to the real economy, endogenous financial cycles); **up-scale model to euro area**.
3. More **sophisticated expectation formation mechanisms**, e.g. VAR expectations, or more forward looking expectation mechanisms.

Appendix

Thank you for your attention!

Further details on the agent-based model are included below.

Limitations

The following limitations apply for our work:

- Model takes a **short- to medium term perspective** due omission of some drivers of long-term economic growth:
  - no demographic change (population growth)
  - no productivity growth of labor due to increased skills and competences (education)
  - no effect on government financing conditions (e.g. interest rates) due to increased government debt and deficit levels
- some **structural features of labor market** not incorporated:
  - no skill mismatches and other structurally determined labor market frictions
  - no migration from workers active on labor market (employed and unemployed) to inactive persons and vice versa (no depiction of 'hidden labor force')
- **no structural differences** between **firms** producing for **domestic** market and **exporting** firms (though empirical evidence suggests the contrary)
- **no correlation** assumed between structural **features of firms** (e.g. size) and **technological parameters** derived from IOTs (e.g. no economies of scale)

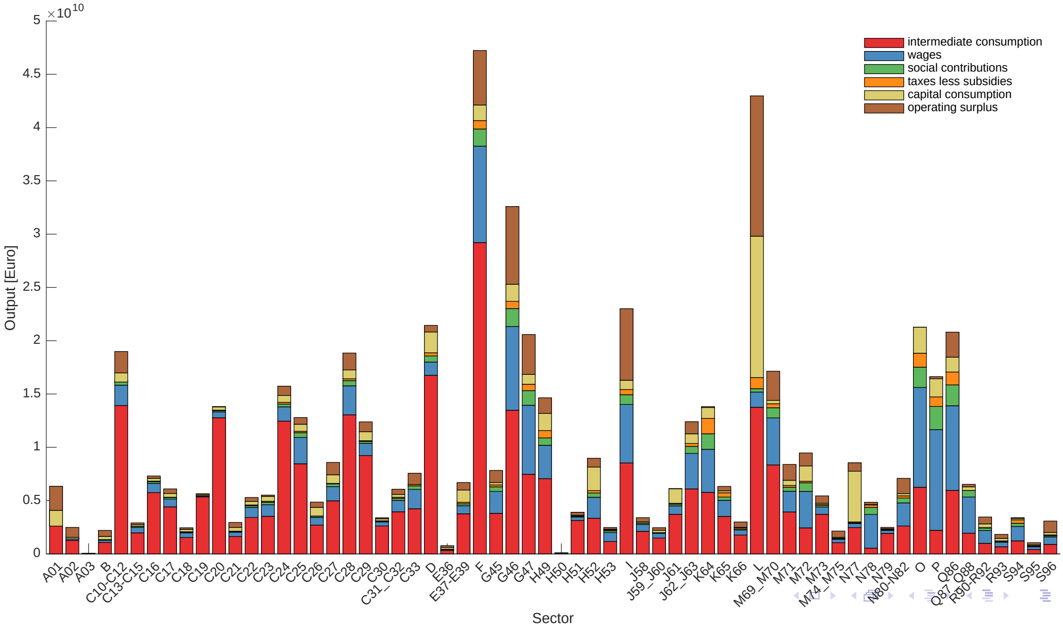
These issues will be **addressed** in the ongoing **further development** of the model!

IO Sectors - NACE Rev. 2 Classification

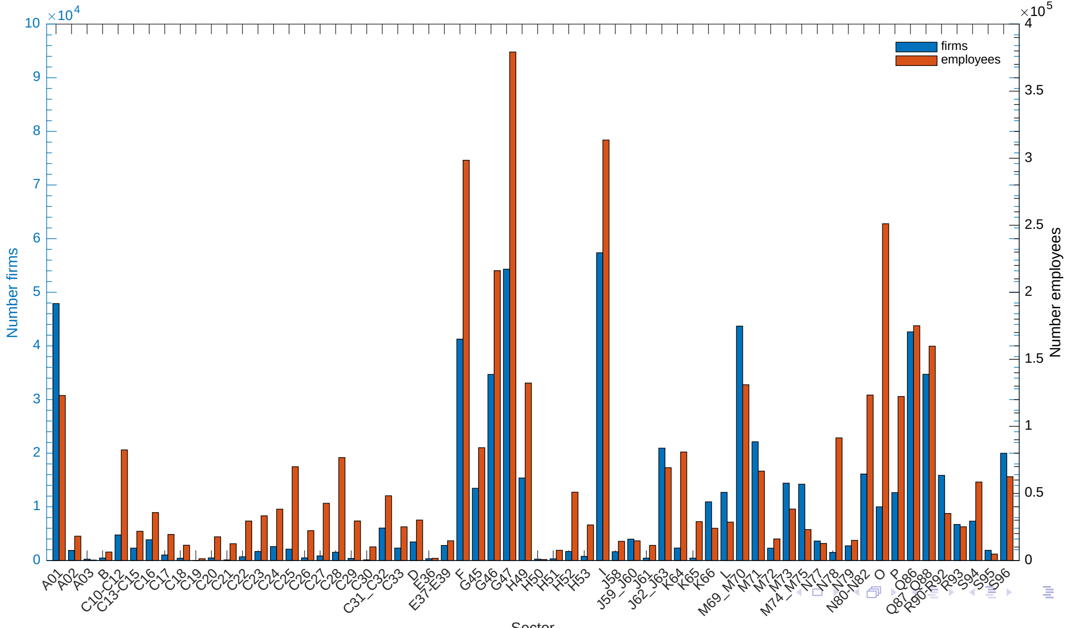
Statistical classification of economic activities in the European Community

	NACE Rev. 2	Description
1	A	Agriculture, forestry and shing
2	B, C, D and E	Manufacturing, mining and quarrying and other industry
3	F	Construction
4	G, H and I	Wholesale and retail trade, transportation and storage, accommodation and food service activities
5	J	Information and communication
6	K	Financial and insurance activities
7	L	Real estate activities*
8	M and N	Professional, scientific, technical, administration and support service activities
9	O, P and Q	Public administration, defence, education, human health and social work activities
10	R, S, T and U	Other services

Parameter setting: Initial Output/Cost Structure



Parameter setting: Initial number of firms/employees



DSGE Model

As a comparison, we employ the two-country model of [Breuss and Rabitsch, 2009], which is based on [Smets and Wouters, 2003]:

- Two countries: Home (Austria), Foreign (Euro Area),
- Domestic and foreign tradable goods, i.e. countries specialize in production of one good; consumption and investment are an index over home and foreign goods subject to constant elasticity of substitution,
- Firms produce using capital and labor services (Cobb-Douglas)
- households receive disutility from working and utility from consumption, own the capital stock which they rent to firms for production,
- sticky prices and wages according to Calvo price setting mechanism, some degree of power by firms and households to set prices and wages,
- complete financial markets,
- capital adjustment costs.

The DSGE model is estimated using Bayesian methods on a set of 13 variables for the same time period as the ABM (1997:Q1-2010:Q1).

$$
\begin{aligned}
GDP &= \overbrace{\sum_{i=1}^{611278}(1-\tau_i^Y)P_i(t)Y_i(t)}^{\text{Total sales of goods and services}} - \overbrace{\sum_{g,s,i\in I_s}\bar{P}_g(t)a_{sg}\frac{Y_i(t)}{\beta_i}}^{\text{Intermediate inputs}} \quad \text{(Production approach)} \\
&= \overbrace{\sum_{h=1}^{8248321} C_h(t)}^{\text{Household consumption}} + \overbrace{\sum_j C_j(t)}^{\text{Government consumption}} + \overbrace{\sum_{h=1}^{8248321} I_h(t) + \sum_{i=1}^{611278} \bar{P}^{CF}(t)I_i(t)}^{\text{Gross fixed capital formation}} \\
&+ \overbrace{\sum_{i=1}^{611278} P_i(t)\Delta S_i(t) + \sum_{g,s,i\in I_s}\bar{P}_g(t)\left(\Delta M_{ig}(t) - a_{sg}\frac{Y_i(t)}{\beta_i}\right)}^{\text{Changes in inventories}} + \overbrace{\sum_l (C_l(t)}^{\text{Exports}} \\
&- \overbrace{\sum_m P_m(t)Q_m(t))}^{\text{Imports}} - \overbrace{\sum_i \tau_i^Y P_i(t)Y_i(t)}^{\text{Net taxes on products}} \quad \text{(Expenditure approach)} \\
&= \underbrace{(1+\tau^{SIF})\bar{P}^{HH}(t)\sum_{h=1}^{8248321} w_h(t)}_{\text{Compensation of employees}} + \underbrace{\sum_{i=1}^{611278}\left(\Pi_i(t) + r(t)L_i(t) + \bar{P}^{CF}(t)\frac{\delta_i}{\kappa_i}Y_i(t)\right)}_{\text{Gross operating surplus and mixed income}} \\
&+ \underbrace{\sum_i \tau_i^K P_i(t)Y_i(t)}_{\text{Net taxes on production}} \quad \text{(Income approach)}
\end{aligned}
$$

Firms: Demand & sales - search and matching

Demand: each firm i experiences demand $Q_i^d(t)$ from consumers.

The level of demand: determined by consumers after the firm has set its price and carried out production $Y_i(t)$,
$\rightarrow$ and is subject to the search and matching mechanism specifying the visiting consumers of firm i:

$$Q_i^d(t) \begin{cases} < S_i(t-1) + Y_i(t) & \text{if demand from visiting consumers is smaller than supply} \\ = S_i(t-1) + Y_i(t) & \text{if demand from visiting consumers exactly matches supply} \\ > S_i(t-1) + Y_i(t) & \text{if demand from visiting consumers is larger than supply from } i \text{ ,} \end{cases}$$

where $S_i(t-1)$ is the inventory of finished goods.
Sales are then the realized demand dependent on the supply available from firm i after the production process has taken place:

$$Q_i(t) = \min(S_i(t-1) + Y_i(t), Q_i^d(t)) \,. \tag{14}$$

General Government: Revenues $Y^G(t)$

$$
\begin{aligned}
Y^G(t) = & \overbrace{(\tau^{SIF} + \tau^{SIW})\bar{P}^{HH}(t) \sum_{h \in H^E(t)} w_h(t)}^{\text{Social security contributions}} + \overbrace{\tau^{INC}(1-\tau^{SIW})\bar{P}^{HH}(t) \sum_{h \in H^E(t)} w_h(t)}^{\text{Labour income taxes}} \\
& + \overbrace{\tau^{VAT} \sum_h C_h(t)}^{\text{Value added taxes}} + \overbrace{\tau^{INC}(1-\tau^{FIRM})\theta^{DIV}\left(\sum_i \max(0,\Pi_i(t)) + \max(0,\Pi_k(t))\right)}^{\text{Capital income taxes}} \\
& + \overbrace{\tau^{FIRM}\left(\sum_i \max(0,\Pi_i(t)) + \max(0,\Pi_k(t))\right)}^{\text{Corporate income taxes}} + \underbrace{\tau^{CF} \sum_h I_h(t)}_{\text{Taxes on capital formation}} \\
& + \underbrace{\sum_{s,i \in I_s} \tau_i^Y P_i(t) Y_i(t)}_{\text{Net taxes/subsidies on products}} + \underbrace{\bar{P}^{CF}(t) \sum_i \tau_i^K K_i(t)}_{\text{Net taxes/subsidies on production}} + \underbrace{\tau^{EXPORT} \sum_l C_l(t)}_{\text{Export taxes}} .
\end{aligned}
\tag{15}
$$

General Government: Deficit & Debt

The **government deficit** (or surplus) resulting from its redistributive activities is

$$\begin{aligned}\Pi^G(t) = & \overbrace{Y^G(t)}^{\text{Government revenues}} - \overbrace{\sum_j C_j(t)}^{\text{Government consumption}} - \overbrace{r^G L^G(t)}^{\text{Interest payments}} \\ & \underbrace{- \sum_{h \in H^{inact}} \bar{P}^{HH}(t) sb^{inact} + \sum_{h \in H^U(t)} \bar{P}^{HH}(t) w_h(t) + \sum_h \bar{P}^{HH}(t) sb^{other}}_{\text{Social benefits and transfers}}\end{aligned} \tag{16}$$

The **government debt** is determined by the year-to-year deficits/surpluses of the government sector:

$$L^G(t) = L^G(t-1) + \Pi^G(t) \tag{17}$$

The Banking Sector

The bank takes deposits from firms and households, and extends a total amount of loans $L^{tot}(t) = \sum_{i=1}^{I} L_i(t)$

The bank will grant a loan to firm i up to the point where the borrower's leverage (or loan-to-value) ratio after the loan,

$$\frac{L_i(t)}{\bar{P}^{CF}(t) K_i(t)} \leq \zeta^{LTV} \tag{18}$$

is below ζ^{LTV}, which is a constant.

Furthermore, the bank is subject to minimum capital requirements, i.e. it can only extend total loans up to a maximum multiple of its equity base or net worth $E^B(t)$.

The interest rate $r(t)$ for bank credit to firms is determined by means of a fixed risk premium μ over the policy rate $\bar{r}(t)$ set by the central bank according to a Taylor rule:

$$r(t) = \bar{r}(t) + \mu \quad . \tag{19}$$

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