Economic forecasting with an agent-based model

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Systemic Risk and Network Dynamics
An EEP-ASA-RISK crosscutting project

Economic forecasting

- **Statistical models** using (mostly linear) time series analysis
  - offer **good forecasting performance**
  - **large-scale macroeconometric models** that use large amounts of data are possible
  - but are **weak in providing explanation** and interpretation of economic events
- **DSGE** and other models derived from economic theory
  - **provide explanation** and interpretation of economic events
  - by depicting the **micro-founded behavior** of agents
  - but for methodological reasons are restricted to **smaller models** with fewer variables than statistical models
- **Agent-based models (ABMs)**
  - **combines advantages** from large-scale statistical models and models derived from theory
  - can be **large-scale and derived from economic theory** at the same time
  - can compete with other models in out-of-sample prediction performance

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Agent-based Modeling

Agent-based models (ABMs) are **computer simulation models** with the following features:

- They model **individual agents** and their individual decisions (decentralized decision making).
- Depict **emergent patterns** from micro-processes aggregate to 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.
- Account for **local interaction networks** between agents
- Based on **micro-foundations** - **big-data** can be included.
- **Very large models** that incorporate **low level details** possible - supercomputing needed to exceed a certain model size.

Agent-based model for the Austrian economy

- Incorporates **all economic activities** (producing and distributive transactions) as classified by the European system of accounts (ESA).
- Includes **all economic entities**, i.e. all juridical and natural persons, are represented by agents (at a scale of 1:10).
- Integrates data from national accounts, input-output tables, government statistics, census data and business surveys.
- Has no unidentified parameters and **does <u>not</u> require calibration**.
- → Avoids related problems such as a transient phase ("burn-in") that has to be disregarded.
- **Empirical validation:** compare out-of-sample prediction performance of the ABM with that of autoregressive-moving-average (ARMA) and vector autoregressive (VAR) models estimated on the same data set.

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Literature and Related Work

This model is in part based on the results of the EC FP7 project **CRISIS**[1] and in particular on the work of

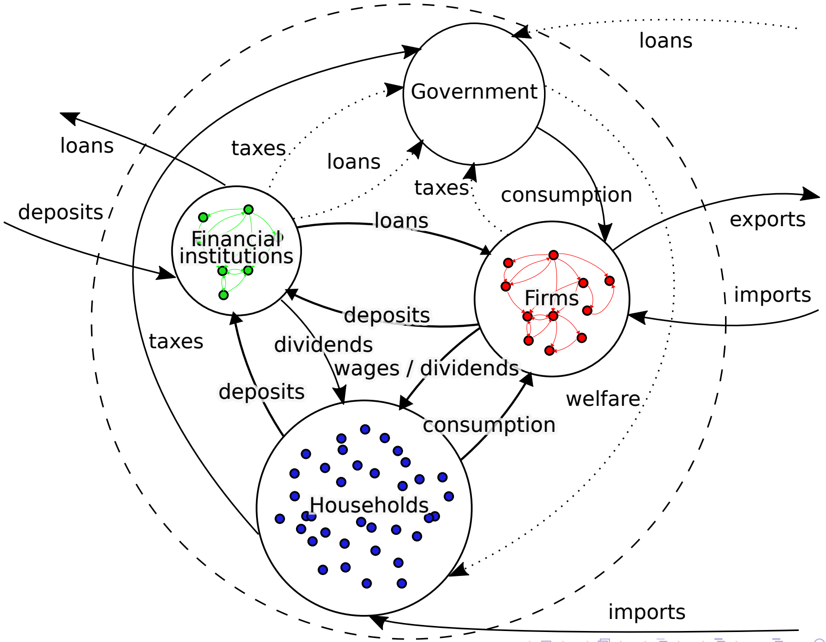
- [Delli Gatti et al., 2011]: provided **methodological framework** (Macroeconomics from the bottom-up).
- [Assenza et al., 2015]: **Starting point** for this model (macroeconomic ABM with capital and credit).
- [Klimek et al., 2015, Poledna and Thurner, 2016, Leduc et al., 2016, Poledna et al., 2016]: **Related work** - systemic risk in financial networks, bail-in vs. bail-out, Basel III regulation.

[1] http://www.crisis-economics.eu, grant agreement no. 288501.

Individual behavior, market processes and networks

- Behavior (level of the agent's control variables) is **not (necessarily)** the **outcome of** an **optimization** process.
- Generally behavior changes adaptively according to **rules of thumb** and **expectations about the future**.
- **Multiple markets** (labor, consumption, loans, intermediate goods/services, gov. bonds, etc.)
- Markets are fully **decentralized** and characterized by a continuous **search and matching process**.
- **Complex networks** (supply chain, bank-firm network, etc.)
- **Input-output model** with 64 industries, all goods and services are endogenously produced.

Major Economic Agents and their Interactions



Non-financial and financial corporations (firms): Economic Flows

- $+$ Output (P.1)[2] $\rightarrow$ part of which results in realized sales
- - 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)

[2] The ESA code is given in brackets.

Parameter setting: European system of accounts

- National accounts
- Input-output tables
- Government statistics
- Demographic statistics
- 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

Parameter setting: initial Output/Cost Structure

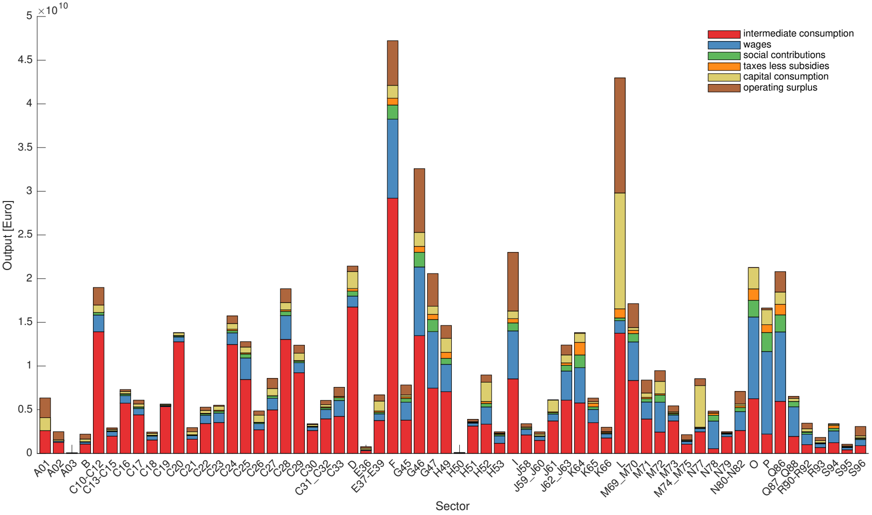


Figure: Distribution of output and cost structure by sector used as initial values for model simulations from observed data of Austria

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Parameter setting: initial number of firms/employees

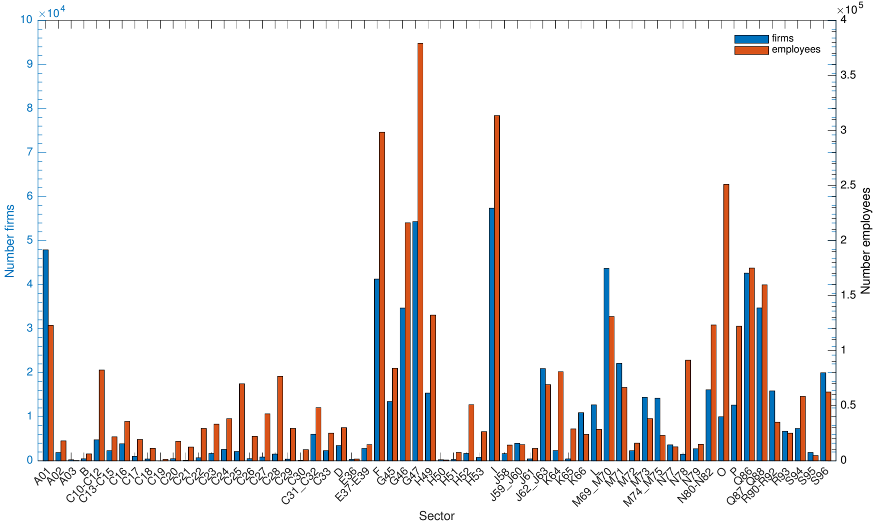

Figure: Distribution of number of firms and employees by sector used as initial values for model simulations from observed data of Austria

Parameter setting: initial bank-firm network

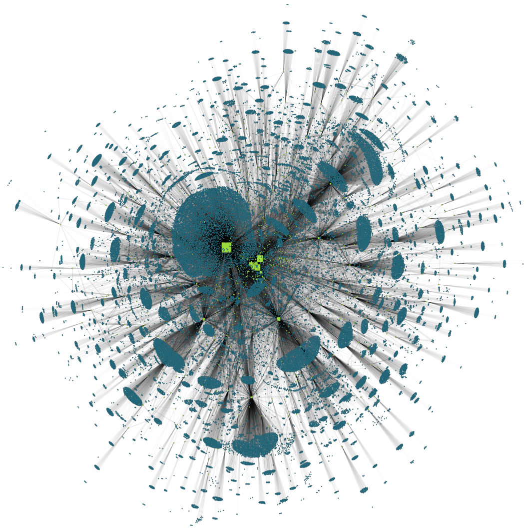

Figure: Reconstructed bank-firm network of 796 banks and 51 980 companies in Austria [Hinteregger et al., 2017]. Node size corresponds to the total assets held by each node.

Firms: Expectations

Expectations: formed according to an autoregressive-moving-average (**ARMA**) model. ARMA models - general form:

$$x(t) = \sum_{p=1}^{P} \alpha_p x(t-p) + \sum_{q=1}^{Q} \beta_q \epsilon(t-q) + \epsilon(t). \tag{1}$$

Dependent variable $x(t)$ explained by its lags, $x(t-p)$, up to the order P and by the lags of the error term, $\epsilon(t-q)$, up to order Q.
Optimal lag orders turn out to be $P = Q = 1$ (by Akaike's information criterion).
We infer expected real growth $[gr^e(t)]$ and the inflation rate $[\pi^e(t)]$ from agents' predictions of (expected) gross value added (GVA, real and in log levels) and GVA deflator (2010=100), respectively:

$$GVA^e(t) = \alpha^{gva} GVA(t-1) + \beta^{gva} \epsilon^{gva}(t-1) + \epsilon^{gva}(t) \tag{2}$$

$$\pi^e(t) = \alpha^{\pi} \pi(t-1) + \beta^{\pi} \epsilon^{\pi}(t-1) + \epsilon^{\pi}(t) \tag{3}$$

Firms: Supply choice & Pricing

Supply choice/demand expectations: firm forms expectations $Q_i^e(t)$ about demand for its product. Firm computes expected real growth rate $gr^e(t)$ to update previous period's demand $Q_i^d(t-1)$, adapts its desired scale of activity $Q_i^s(t)$:

$$Q_i^s(t) = Q_i^e(t) = Q_i^d(t-1)(1+\gamma^e(t)) \tag{4}$$

Pricing: according to expected inflation rate $\pi^e(t)$, cost-structure, target unit profit margin:

$$\begin{aligned} P_i(t) = {} & \overbrace{\frac{w_i(t)(1+\tau^{SIF})\bar{P}^{HH}(t-1)(1+\pi^e(t))}{\alpha_i(t)}}^{\text{Unit labour costs}} + \overbrace{\frac{1}{\beta_i}\sum_g a_{sg}\bar{P}_g(t-1)(1+\pi^e(t))}^{\text{Unit Material costs}} \\ & + \underbrace{\frac{\delta_i}{\kappa_i}\bar{P}^{CF}(t-1)(1+\pi^e(t))}_{\text{Unit capital costs}} + \underbrace{\tau_i^Y P_i(t-1)(1+\pi^e(t))}_{\text{Unit net taxes/subsidies products}} \\ & + \underbrace{\frac{\tau_i^K}{\kappa_i\omega}\bar{P}^{CF}(t-1)(1+\pi^e(t))}_{\text{Unit net taxes/subsidies production}} + \underbrace{\bar{\pi}_i P_i(t-1)(1+\pi^e(t))}_{\text{Target unit operating surplus}} \end{aligned} \tag{5}$$

Firms: Output & Investment

Output: $Y_i(t)$ produced via intermediate inputs $M_{ig}(t)$, labour (no. of employees $N_i(t)$), capital $K_i(t)$ with a fixed coefficient (Leontief) technology. α_i, β_i and κ_i: productivity coefficients, a_{sg} technologically determined input coefficients:

$$\begin{aligned} Y_i(t) = \min\Bigg(& Q_i^s(t), \frac{\beta_i}{a_{s1}} M_{i1}(t-1), \frac{\beta_i}{a_{s2}} M_{i2}(t-1), \ldots, \\ & \frac{\beta_i}{a_{sg}} M_{ig}(t-1), \alpha_i(t) N_i(t), \kappa_i K_i(t-1) \Bigg) . \end{aligned} \tag{6}$$

Investment: according to depreciation δ_i, productivity of capital κ_i, and desired scale of activity $Q_i^s(t)$,

$$I_i^d(t) = \frac{\delta_i}{\kappa_i} Q_i^s(t) = \frac{\delta_i}{\kappa_i} Q_i^e(t) = \frac{\delta_i}{\kappa_i} Q_i^d(t-1)[1 + \gamma^e(t)] \quad . \tag{7}$$

Households: Economic Flows

- + 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)

Households: consumption & investment

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

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

and on **investment:**

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

where ψ is the marginal propensity to consume and ψ^H the marginal propensity to invest out of expected income.

Savings is the difference between current disposable income Y_h and actual consumption expenditure C_h, used to accumulate financial wealth

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

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General Government: Economic Flows

Government mainly acts as a **'redistributional' entity**: 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)

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General Government: Revenues

Revenues of the general government are: $Y^G(t) =$

$$\overbrace{(\tau^{SIF} + \tau^{SIW})\bar{P}^{HH}(t) \sum_{h \in H^E(t)} w_h(t)}^{\text{Social security contributions}} + \overbrace{\sum_{s, i \in I_s} \tau_i^Y P_i(t) Y_i(t)}^{\text{Net taxes/subsidies on products}}$$

$$+ \overbrace{\tau^{INC}(1 - \tau^{SIW})\bar{P}^{HH}(t) \sum_{h \in H^E(t)} w_h(t)}^{\text{Labour income taxes}} + \overbrace{\tau^{VAT} \sum_h C_h(t)}^{\text{Value added taxes}}$$

$$+ \overbrace{\tau^{INC}(1 - \tau^{FIRM})\theta^{DIV} \left(\sum_i \max(0, \Pi_i(t)) + \max(0, \Pi_k(t)) \right)}^{\text{Capital income taxes}} \quad (11)$$

$$+ \overbrace{\tau^{FIRM} \left(\sum_i \max(0, \Pi_i(t)) + \max(0, \Pi_k(t)) \right)}^{\text{Corporate income taxes}} + \overbrace{\tau^{CF} \sum_h I_h(t)}^{\text{Taxes on capital formation}}$$

$$+ \overbrace{\bar{P}^{CF}(t) \sum_i \tau_i^K K_i(t)}^{\text{Net taxes/subsidies on production}} + \overbrace{\tau^{EXPORT} \sum_l C_l(t)}^{\text{Export taxes}} .$$

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General Government: deficit & debt

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

$$\Pi^G(t) = \overbrace{Y^G(t)}^{\text{Government revenues}} - \overbrace{\sum_j C_j(t)}^{\text{Government consumption}} - \overbrace{r^G L^G(t)}^{\text{Interest payments}} \\ \underbrace{- \sum_{h \in H^{inact}} \bar{P}^{HH}(t) sb^{inact} + \sum_{h \in H^U(t)} \bar{P}^{HH}(t) w_h(t) + \sum_h \bar{P}^{HH}(t) sb^{other}}_{\text{Social benefits and transfers}} . \tag{12}$$

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

$$L^G(t) = L^G(t-1) + \Pi^G(t) . \tag{13}$$

Out-of-sample Prediction Performance: Growth

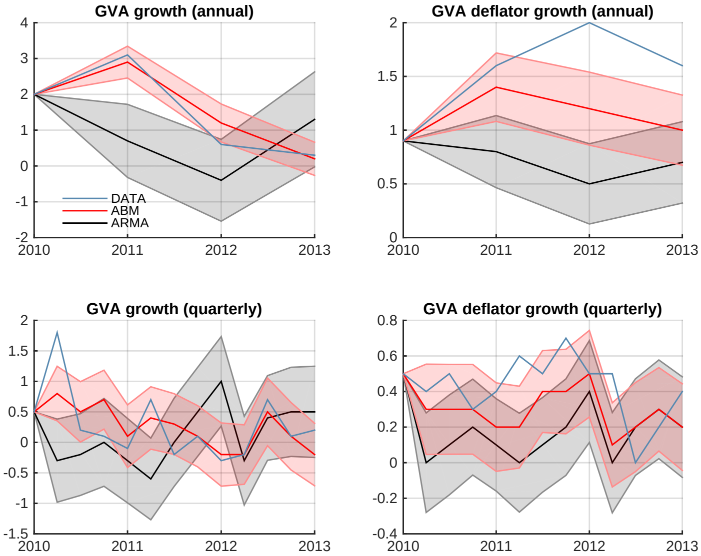

Figure: Comparison of ABM simulations (red), ARMAX(1,1) (black), and observed Eurostat data for Austria (blue) for a forecast horizon of 12 quarters.

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Out-of-sample Prediction Performance: Annual levels

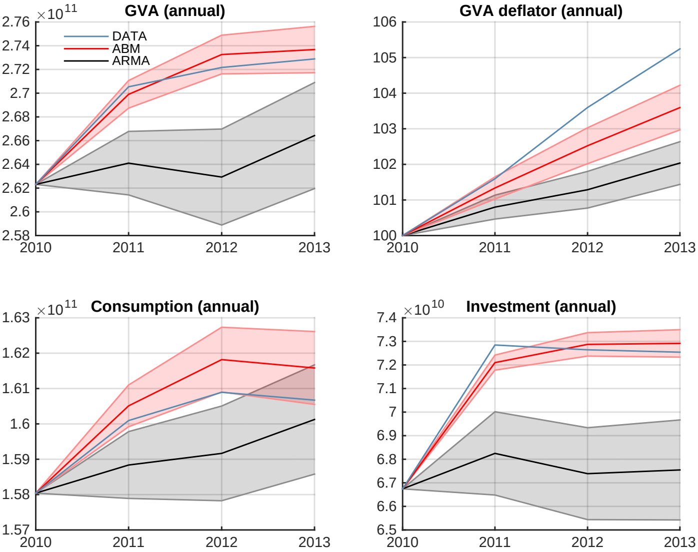

Figure: Comparison of ABM simulations (red), ARMAX(1,1) (black), and observed Eurostat data for Austria (blue) for a forecast horizon of 12 quarters.

Out-of-sample Prediction Performance: Quarterly levels

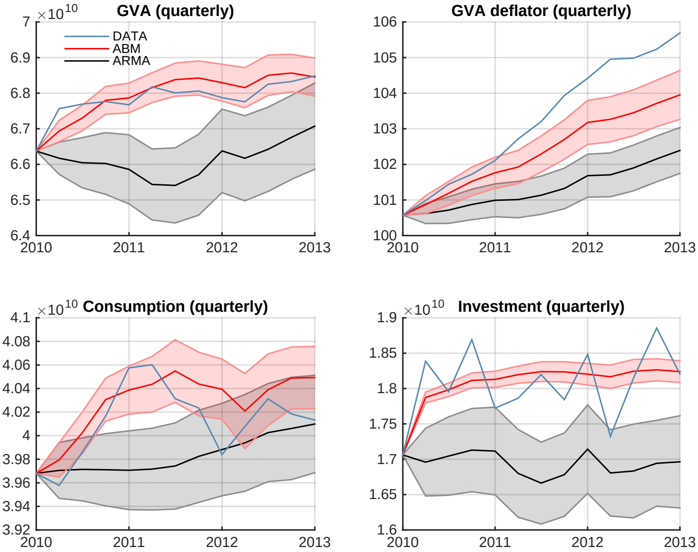

Figure: Comparison of ABM simulations (red), ARMAX(1,1) (black), and observed Eurostat data for Austria (blue) for a forecast horizon of 12 quarters.

Out-of-sample Prediction Performance: Sectoral GVA

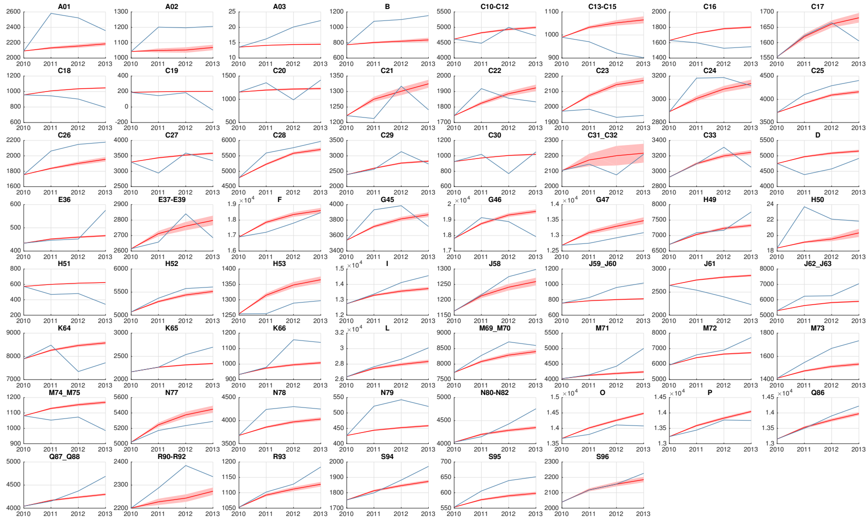

Figure: Comparison of sectoral gross value added (GVA) for ABM simulations and observed data of Austria from 2010 to 2013

Out-of-sample Prediction Performance: RMSE

	GVA	GVA deflator	Household consumption	Investment
ABM	*RMSE-statistic for different forecast horizons*			
1q	0.42	0.28	0.88	3.75
2q	0.49	0.46	1.12	3.56
4q	0.54	0.85	1.68	4.18
8q	0.71	1.71	2.01	3.60
12q	0.58	2.44	2.24	4.16
ARMAX(1,1)	*RMSE-statistic relative to ABM (ABM=100)*			
1q	100.14	98.99	81.09	88.01
2q	156.82	118.69	97.10	102.21
4q	246.93	120.76	135.41	137.84
8q	328.38	97.57	183.76	224.35
12q	300.61	139.97	145.81	227.19
VARX(1)	*RMSE-statistic relative to ABM (ABM=100)*			
1q	101.59	98.58	106.27	83.54
2q	158.17	109.92	115.43	102.38
4q	447.65	148.06	159.29	202.06
8q	428.04	176.33	267.00	326.95
12q	755.43	160.81	295.11	198.91

Table: RMSE-statistic for different forecast horizons of ABM simulations, ARMAX(1,1) and VARX(1) for the forecast period from 2010:Q2-2016:Q4.

Summary

- We develop a **simple ABM** of the Austrian economy without unidentified parameters, that **does not require calibration** and **avoids** related problems such as a **transient phase** that has to be disregarded.
- The structure of the model is chosen to allow easy integration of more detailed data when it becomes available in the future.
- We show that this model is able to **compete** with vector autoregressive (**VAR**) and autoregressivemoving-average (**ARMA**) models in **out-of-sample prediction**.
- **Potential applications** of this ABM include economic forecasting, stress test exercises and predicting the effects of changes in monetary, fiscal, or other macroeconomic policies.

Appendix: 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

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