WIFO ÖSTERREICHISCHES INSTITUT FÜR WIRTSCHAFTSFORSCHUNG

Economic Forecasting with an Agent-based model

Sebastian Poledna, Serguei Kaniovski

WIFO

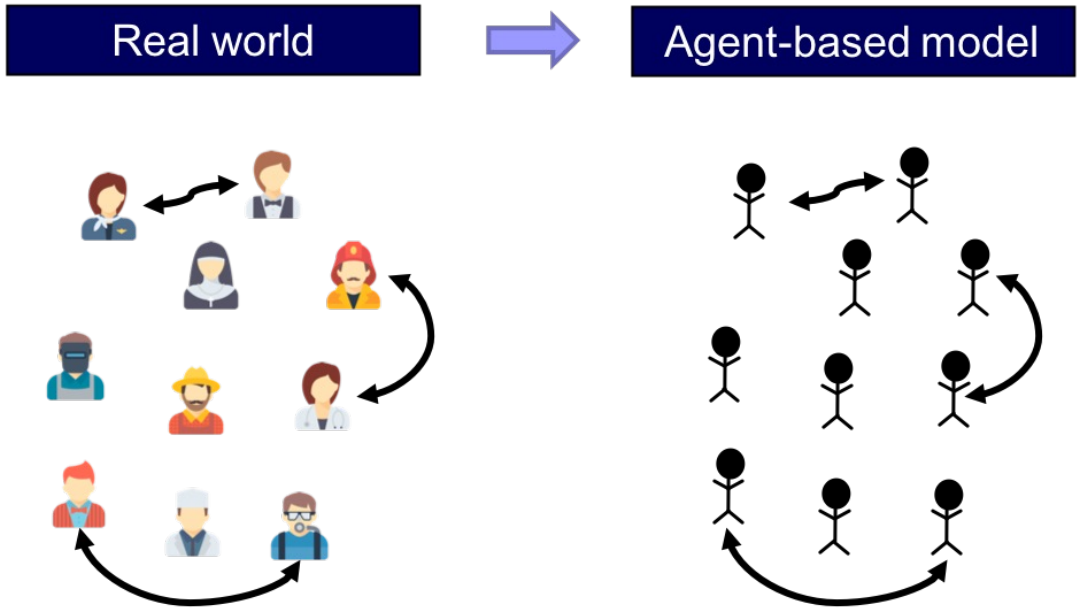
5 February 2026

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 that aggregate to a macro level
- **integrate microdata (**e.g., individuals or firms) to capture the heterogeneity of agents
- leverage **high-performance computing**

ABMs are used across a wide range of disciplines and are now also increasingly used in economics.



"Challenges aside, ABMs are a promising complement to the current crop of macroeconomic models, especially when making sense of the types of extreme macroeconomic movements the world has witnessed for the past decade."(Haldane & Turrell 2018)

Agent-based macroeconomics

Agent-based models explain the evolution of an economy by **simulating** the **micro-level behaviour** of **individual agents** to give a **macro-level** picture**.**

Over the last 15 years, a number of macroeconomic agent-based models have been developed.

Main purposes:

- **Reproduction of stylized facts** and emergent phenomena (bubbles/crashes, divergence/convergence, technological change, etc.)
- **Basis for policy analysis** (fiscal, monetary, innovation, regulation, etc.)
- **Integration with other models** (climate, epidemic, etc.)

The basic structure of these models is similar, but some differ in market protocols and behavioral rules. Dawid & Delli Gatti (2018) compare the models and generalize their key behavioral rules.

General Behavioral Rules in Dawid and Delli Gatti (2018)

Consumption function: $$C_{h,t} = c_y W^y_{h,t} + c_f W^f_{h,t}$$

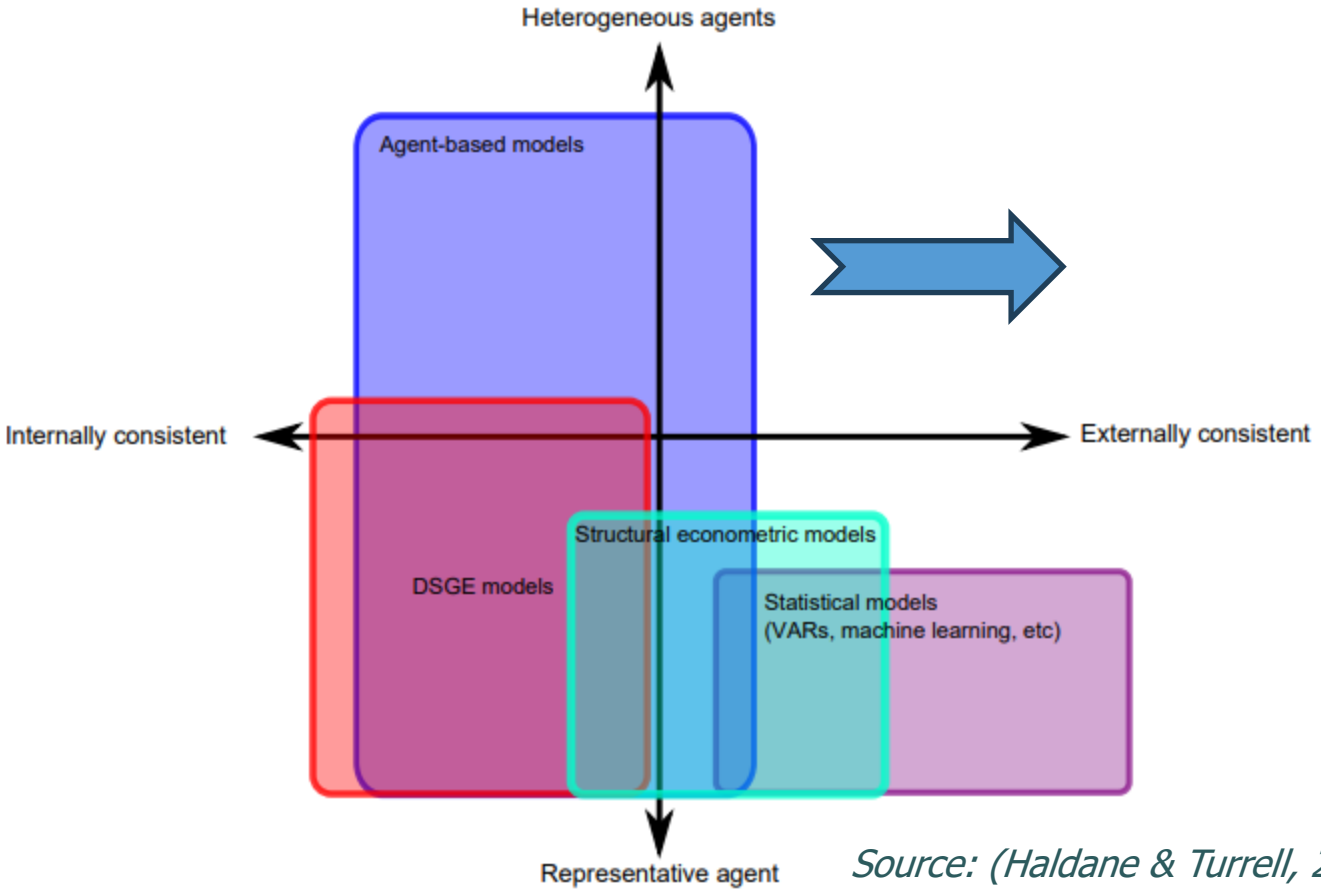
Investment function: $$I_{i,t} = \left(\frac{1}{\omega^T} + \delta^r\right) \hat{K}_{i,t-1} - K_{i,t}$$

Quantity adjustment: $$Q^{D,e}_{i,t} = \begin{cases} Q^{D,e}_{i,t-1}\left(1+\eta^q\right) & \text{if } \Delta_{i,t} < \Delta^m_{i,t} \text{ and } P_{i,t} > P_t \\ Q^{D,e}_{i,t-1}\left(1-\eta^q\right) & \text{if } \Delta_{i,t} > \Delta^M_{i,t} \text{ and } P_{i,t} < P_t \end{cases}$$

Price equation: $$P_{i,t} = \begin{cases} P_{i,t-1}\left(1+\eta^p\right) & \text{if } \Delta_{i,t} < \Delta^m_{i,t} \text{ and } P_{i,t} < P_t \\ P_{i,t-1}\left(1-\eta^p\right) & \text{if } \Delta_{i,t} > \Delta^M_{i,t} \text{ and } P_{i,t} > P_t \end{cases}$$

Production function: $$Y_{i,t} = \min\left(\alpha N_{i,t}, \kappa K_{i,t}\right)$$

Comparison of different types of economic models



Source: (Haldane & Turrell, 2017).

ABMs…

- **combine** advantages from large-scale **statistical models** and models derived from **economic 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

"In principle it might even be possible to create an agent-based economic model capable of making useful forecasts of the real economy, although this is ambitious ... like climate modelling, [it's] a huge undertaking." (Farmer & Foley 2009)

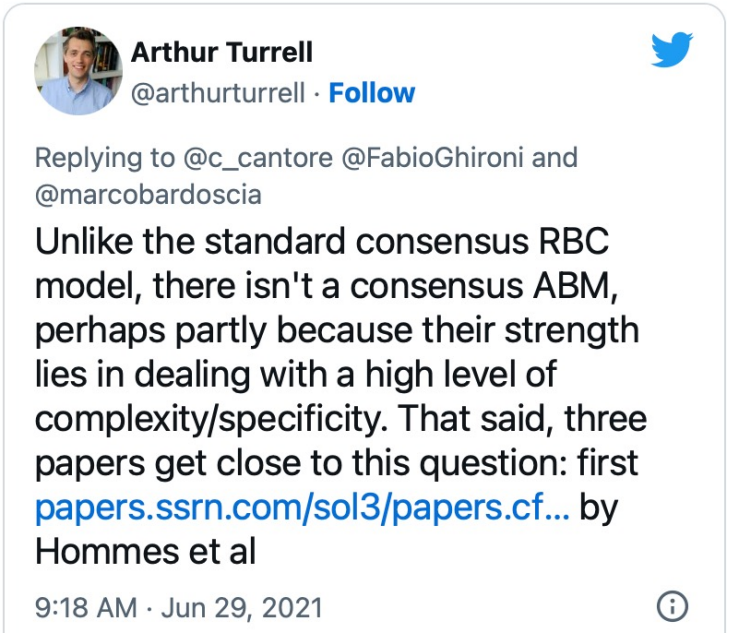
European Economic Review
Volume 151, January 2023, 104306

Economic forecasting with an agent-based model

Sebastian Poledna [a b c g], Michael Gregor Miess [k e a b h], Cars Hommes [d i j c], Katrin Rabitsch [f]

We showed that agent-based economic models:

- can be calibrated to micro and macroeconomic data from national accounts, IO tables, firm-level data, etc.
- are competitive with VAR and DSGE models in out-of-sample forecasting



RebuildingMacroeconomics

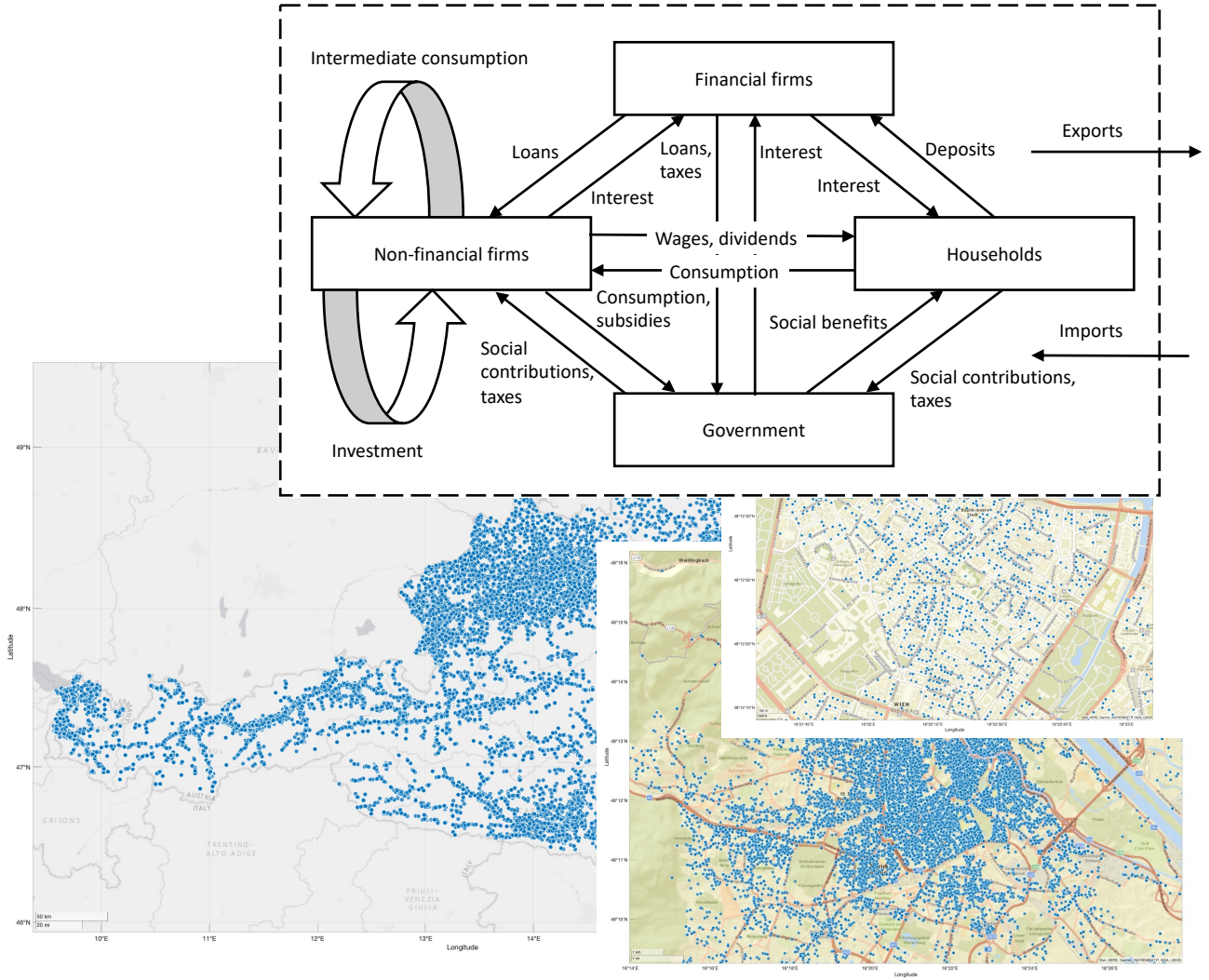
Economic and Social Research Council

COMPLEXITY AND MACROECONOMICS PRIZE

Poledna, S., Miess, M. G., Hommes, C., & Rabitsch, K. (2023)

Agent-based model of Poledna et al. (2023)

- Agent-based model with **explicit sector detail** following **national accounts conventions**;
- intersectoral **input-output** (production network) and **financial linkages**;
- **Rich heterogeneity** (1:1 scale): **~9 million** individuals and **~600,000** firms (Austria)
- **Competitive** out-of-sample **forecast performance**



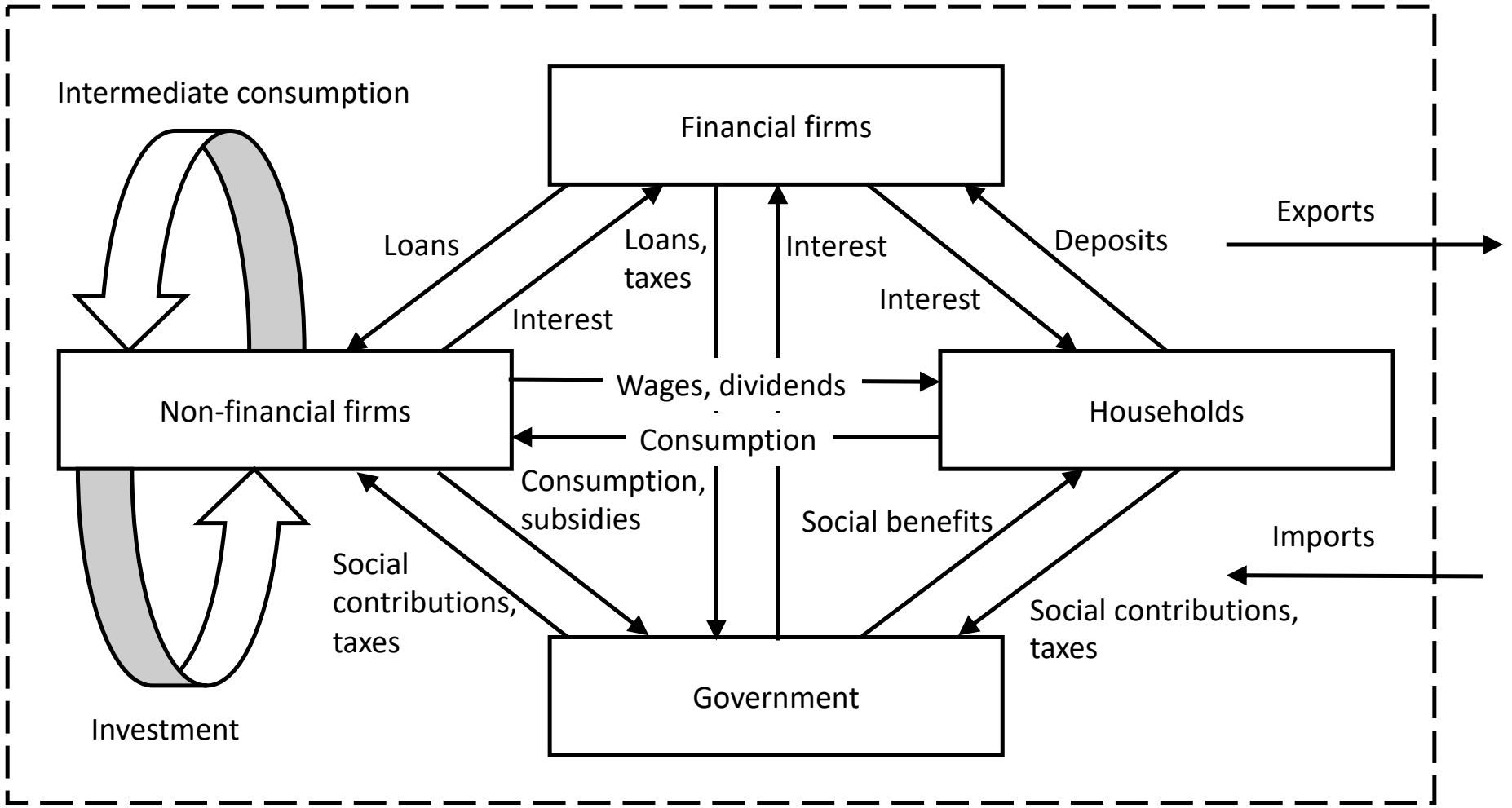
Agents & Markets in the Model

- **Search-and-Match & Bounded Rationality** and **Heuristic Rules** from the literature
- **Bounded Rationality**: Firms and consumers form expectations about future developments (adaptive learning).
- **Firms** in 64 sectors (**NACE**) produce goods (**Leontief technology**), using **labor**, **capital**, and **intermediate inputs** from other firms.
- **Consumption networks** and **supply chains** are formed through *search-and-matching* processes:
  - Firms are randomly "*visited*" by consumers.
  - The **likelihood** of a firm being visited **correlates negatively** with its **offered price** and **positively** with the **size** of the firm.
  - **Inventories** and **involuntary savings** arise from the search-and-matching process.

Agents & Markets in the Model

- The **labor market** is also modeled using search-and-matching.
- **Demand for financing** by firms is based on **expectations** of future cash flow.
- **Banks** grant loans based on firms' financial conditions and with respect to minimum capital requirements.
- The **central bank** follows a **(Euro Area) Taylor Rule**.
- The **general government** acts as a consumer (government consumption) and as a "*redistributional entity*".
- **Exogenous inputs**: supply and demand from the rest of the world.

Agents & Markets in the Model

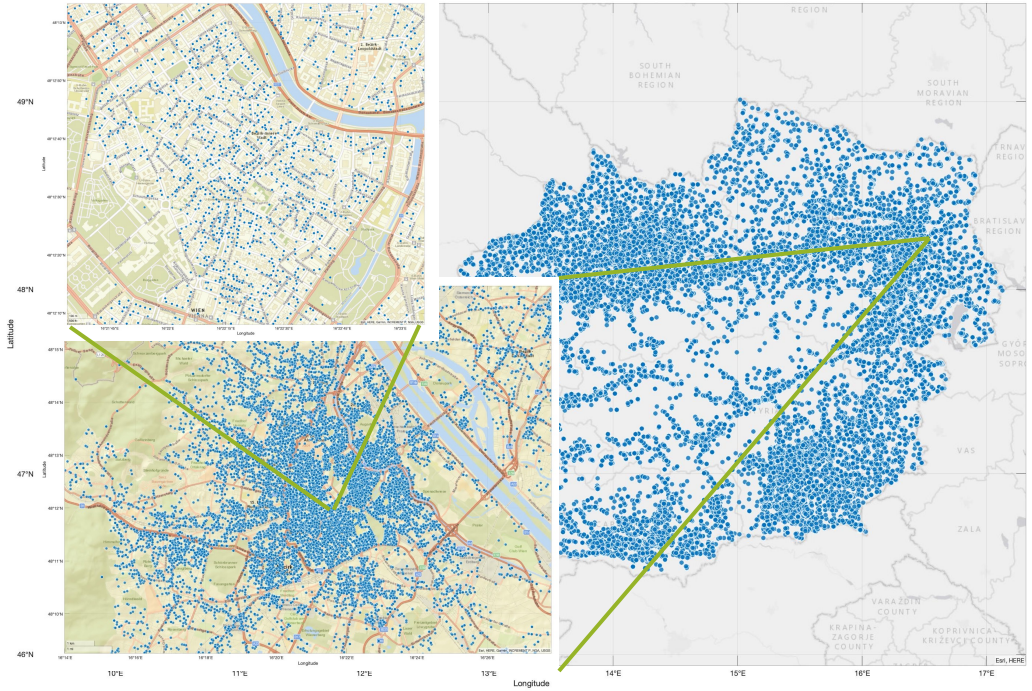


GDP in the ABM according to the production, expenditure, and income approach

$$
\begin{aligned}
GDP(t) = & \underbrace{\sum_i \tau_i^{\mathrm{Y}} P_i(t) Y_i(t) + \sum_h \tau^{\mathrm{VAT}} C_h(t) + \sum_h \tau^{\mathrm{CF}} I_h(t) + \sum_j \tau^{\mathrm{G}} C_j(t) + \sum_l \tau^{\mathrm{EXPORT}} C_l(t)}_{\text{Taxes on products}} \\
& + \underbrace{\sum_i (1-\tau_i^{\mathrm{Y}}) P_i(t) Y_i(t)}_{\text{Total sales of goods and services}} - \underbrace{\sum_i \frac{1}{\beta_i} \bar{P}_i(t) Y_i(t)}_{\text{Intermediate inputs}} \quad \text{(Production approach)} \\
= & \underbrace{\sum_h (1+\tau^{\mathrm{VAT}}) C_h(t)}_{\text{Household consumption}} + \underbrace{\sum_j (1+\tau^{\mathrm{G}}) C_j(t)}_{\text{Government consumption}} + \underbrace{\sum_h (1+\tau^{\mathrm{CF}}) I_h(t) + \sum_i P_i^{\mathrm{CF}}(t) I_i(t)}_{\text{Gross fixed capital formation}} \\
& + \underbrace{\sum_i P_i(t)(Y_i(t) - Q_i(t)) + \bar{P}_i(t) \left(\Delta M_i(t) - \frac{1}{\beta_i} Y_i(t) \right)}_{\text{Changes in inventories}} \\
& + \underbrace{\sum_l (1+\tau^{\mathrm{EXPORT}}) C_l(t)}_{\text{Exports}} - \underbrace{\sum_m P_m(t) Q_m(t))}_{\text{Imports}} \quad \text{(Expenditure approach)} \\
= & \underbrace{\sum_i \tau_i^{\mathrm{Y}} P_i(t) Y_i(t) + \sum_h \tau^{\mathrm{VAT}} C_h(t) + \sum_h \tau^{\mathrm{CF}} I_h(t) + \sum_j \tau^{\mathrm{G}} C_j(t) + \sum_l \tau^{\mathrm{EXPORT}} C_l(t)}_{\text{Taxes on products}} \\
& + \underbrace{\sum_i P_i(t) Y_i(t) - (1+\tau^{\mathrm{SIF}}) \bar{P}^{\mathrm{HH}}(t) N_i(t) w_i(t) - \frac{1}{\beta_i} \bar{P}_i(t) Y_i(t) - \tau_i^{\mathrm{Y}} P_i(t) Y_i(t) - \tau_i^{\mathrm{K}} P_i(t) Y_i(t)}_{\text{Gross operating surplus and mixed income}} \\
& + \underbrace{\sum_i (1+\tau^{\mathrm{SIF}}) \bar{P}^{\mathrm{HH}}(t) N_i(t) w_i(t)}_{\text{Compensation of employees}} + \underbrace{\sum_i \tau_i^{\mathrm{K}} P_i(t) Y_i(t)}_{\text{Net taxes on production}} \quad \text{(Income approach)}
\end{aligned}
$$

Calibration of the ABM

Data type	Data purpose
Census and business demography	Populate the model with realistic numbers of agents-individuals and agents-firms
Input-output *industry × industry* tables (IOTs); all economic activities as classified by the European System of Accounts: 64 industries (NACE-level 2)	Describe the sale and purchase relationships between producers and consumers within an economy, i.e., flows of final and intermediate goods and services defined according to industry outputs tables
Government statistics and sector accounts	Calibrate tax rates, social insurance rates, etc.
National accounts (GDP and main components) and money market interest rates	Estimate exogenous processes and the Taylor rule to determine the policy rate
Statutory guidelines, financial regulation, and banking practices	Determine capital requirements, inflation targets, unemployment benefit replacement rate, etc.



ABM implementations

Five implementations of the ABM have been developed:

- The "reference" implementation is written in MATLAB. In the spirit of Dynare, the model is implemented almost as it is described in the manuscript.
- A Distributed Memory Parallel (DMP-HPC) implementation was developed by Gill et al. (2021) for the Fugaku supercomputer.
- BeforeIT.jl is a Julia-based implementation of the ABM developed by the Bank of Italy.
- A Python-based implementation by the University of Oxford.
- A commercial Java implementation used by Deloitte.

Economic forecasting

	GDP	Inflation	Consumption	Investment	Exports	Imports
VAR(1)	*RMSE-statistic for different forecast horizons*					
1q	0.48	0.73	0.33	1.54	2.17	1.8
2q	0.76	0.68	0.54	2.7	2.98	2.68
4q	1.24	0.65	1.01	5.19	3.53	4.55
8q	1.9	0.69	1.66	9.95	4.57	9.22
12q	2.24	0.71	1.98	15.14	4.65	13.83
ToTEM (III)	*Percentage gains (+) or losses (-) relative to VAR(1) model*					
1q	-27.2 (0.09)	14.4 (0.07)	-49.2 (0.00)	-18.8 (0.03)	14.9 (0.05)	24.2 (0.00)
2q	-56 (0.01)	7.3 (0.09)	-77.5 (0.00)	-28.7 (0.02)	20.4 (0.16)	27.6 (0.01)
4q	-73.4 (0.00)	1.9 (0.71)	-76.7 (0.02)	-16.8 (0.15)	6.8 (0.67)	30.1 (0.02)
8q	-58.5 (0.03)	8 (0.14)	-56.6 (0.18)	15.9 (0.50)	8.7 (0.78)	48 (0.00)
12q	-33.8 (0.29)	6.4 (0.23)	-39.2 (0.07)	41.5 (0.01)	24.7 (0.19)	64.9 (0.03)
CAN-ABM	*Percentage gains (+) or losses (-) relative to VAR(1) model*					
1q	0.6 (0.93)	10.1 (0.07)	-51.5 (0.01)	5.4 (0.49)	-0.7 (0.89)	13.5 (0.20)
2q	4 (0.46)	-0.6 (0.84)	-67.8 (0.02)	13.3 (0.02)	0.8 (0.90)	21.6 (0.07)
4q	17.2 (0.02)	-5.3 (0.27)	-25.3 (0.43)	23.6 (0.08)	-6.1 (0.36)	42.3 (0.02)
8q	20.6 (0.04)	-6.4 (0.19)	7.7 (0.85)	33.5 (0.09)	-15.5 (0.31)	65.9 (0.01)
12q	33.4 (0.00)	-2.4 (0.58)	31.8 (0.67)	43.3 (0.00)	-38.5 (0.17)	79.6 (0.05)

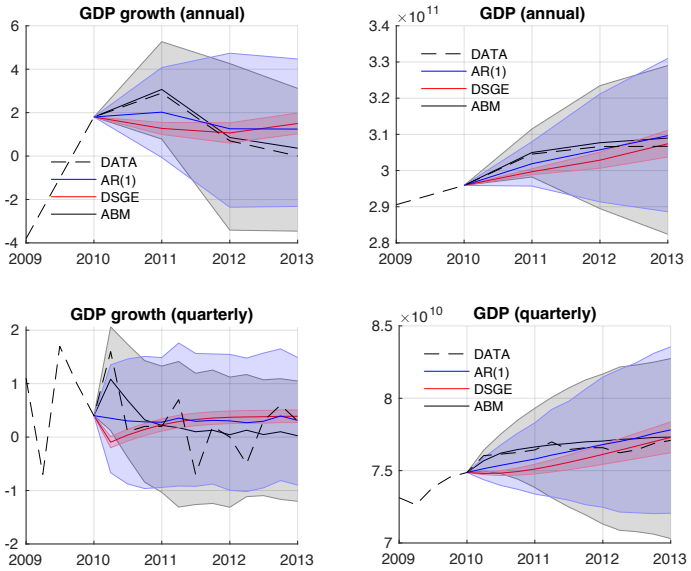
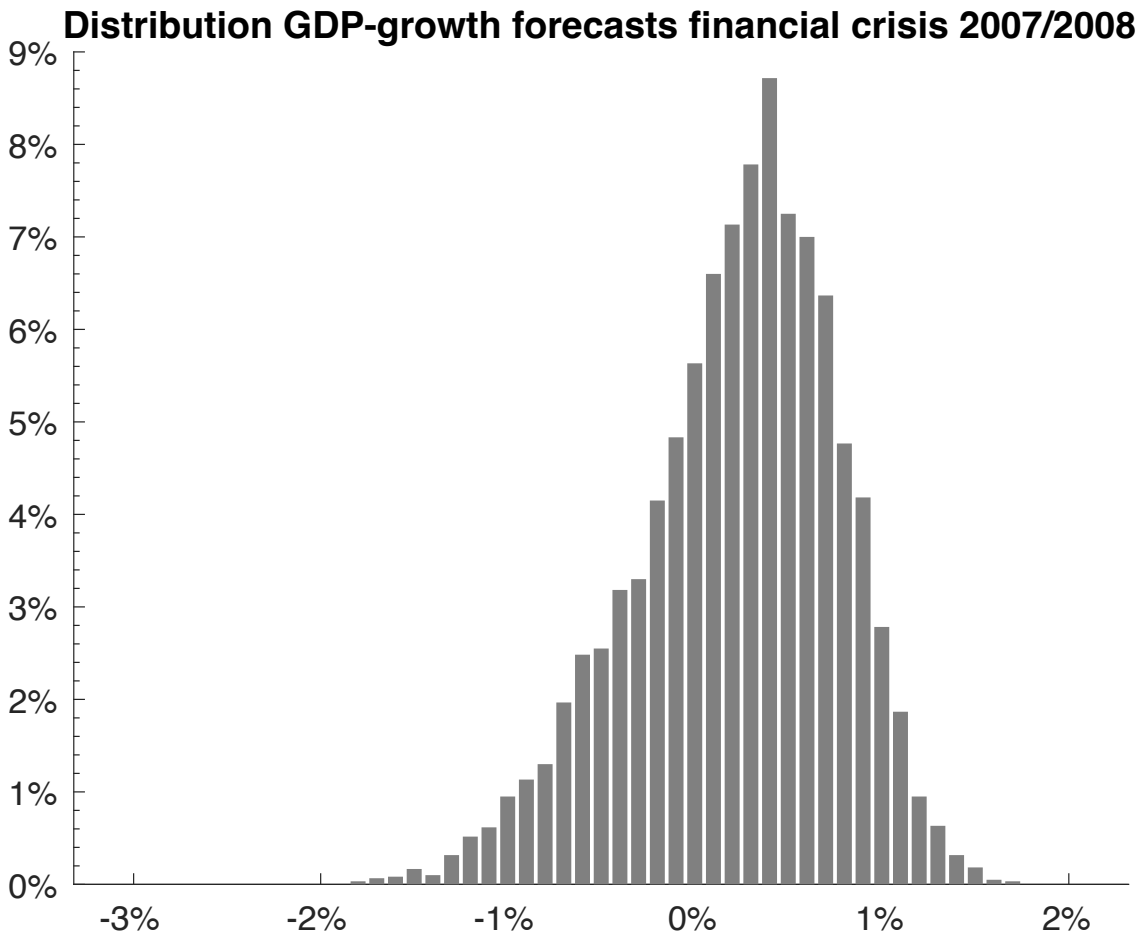


Figure: *Comparison of ABM simulations (black) with AR(1) (blue), DSGE (red), and observed data for Austria (dashed line).*

Table: *RMSE-statistic for main aggregates from ABM simulations in comparison to a VAR(1) and the main DSGE model of the Bank of Canada (ToTEM III) for the forecast period from 2010:Q2-2019:Q4 for Canada.*

Hommes, C., He, M., Poledna, S., Siqueira, M., & Zhang, Y. (2024)

Forecasting financial crisis



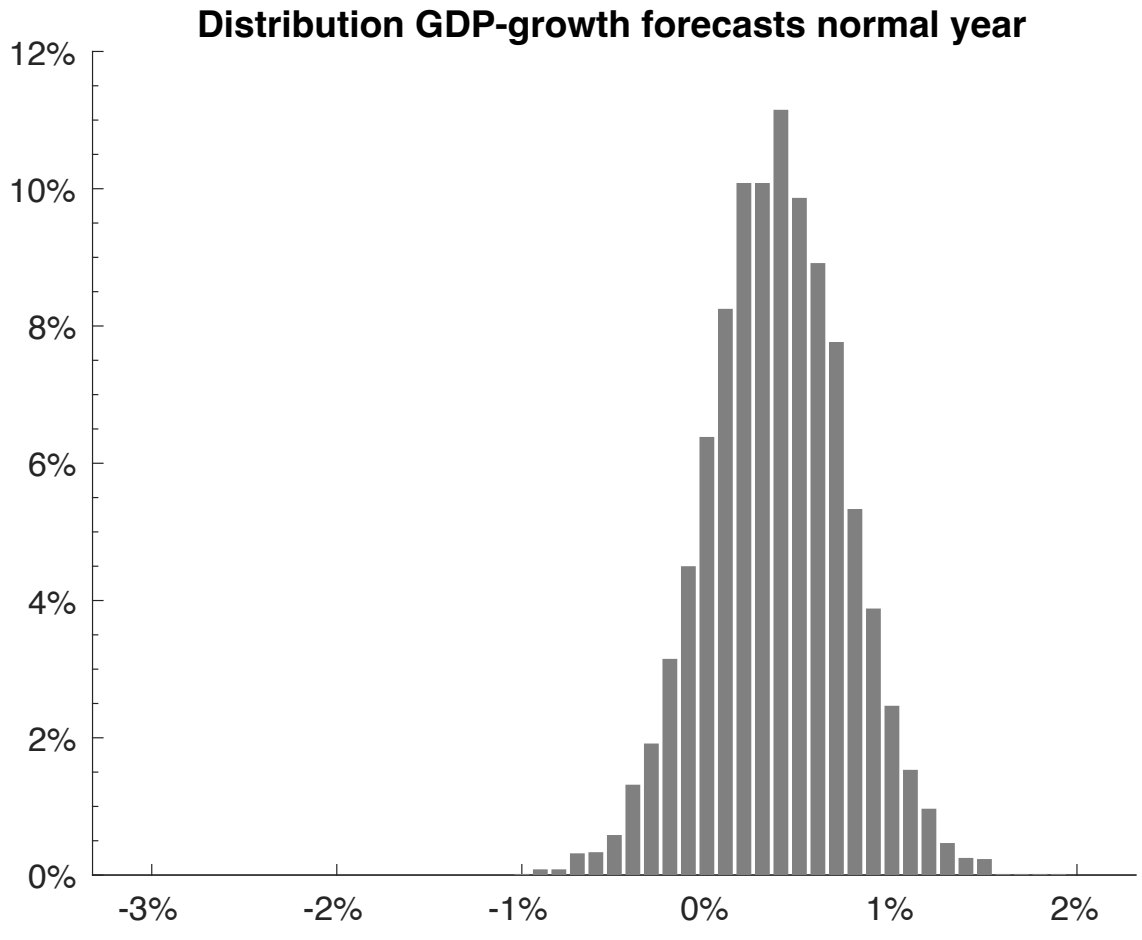
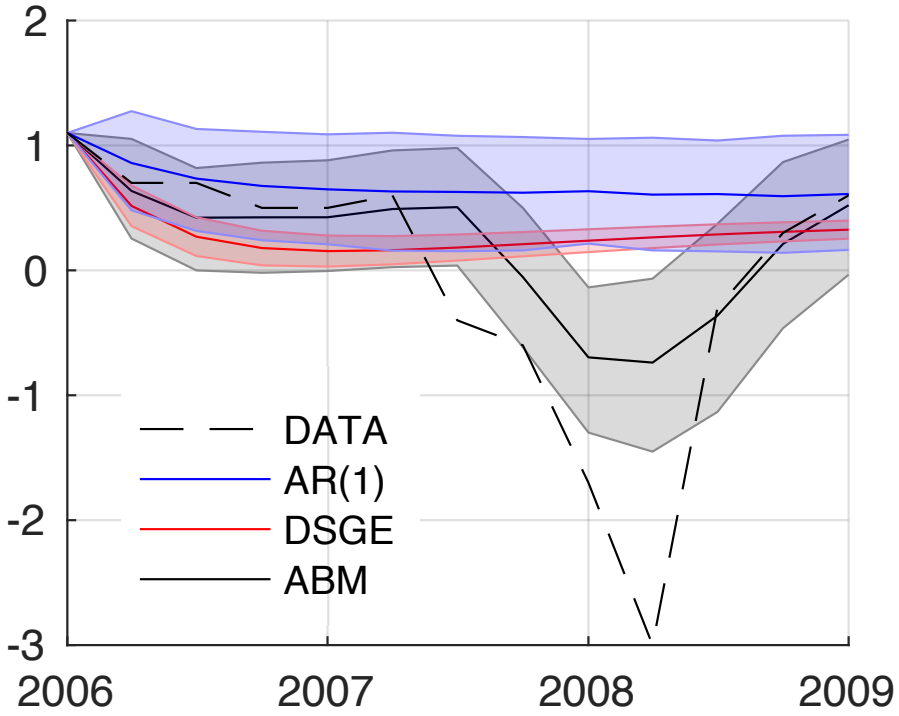


Figure: *Histograms of ABM quarterly GDP-growth rates in the euro area for a "normal" year and the financial crisis of 2007/2008.*

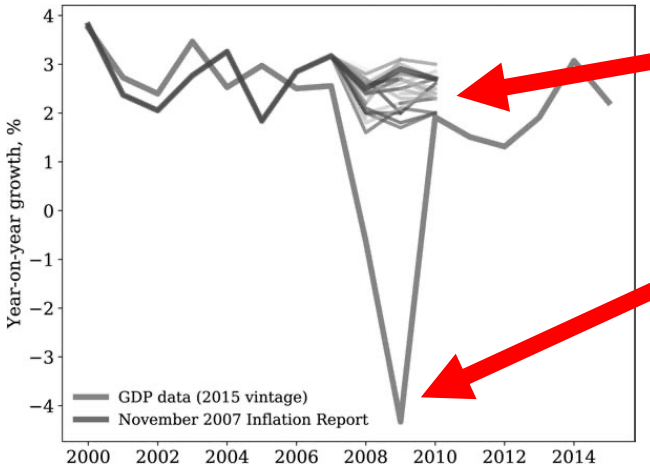
Hommes, C. & Poledna, S. (2023)

Forecasting financial crisis

ABM GDP forecasts from the last quarter of 2006 for the euro area



Range of UK GDP forecasts in 2007



Models' forecasts

Reality

Source: Haldane (2016)

Figure: *Comparison of ABM simulations (black), AR(1) (blue), DSGE (red), and observed Eurostat data for the euro area (dashed line) for a forecast horizon of 12 quarters.*

Hommes, C. & Poledna, S. (2023)

Financial crisis of 2007-2008 in the euro area

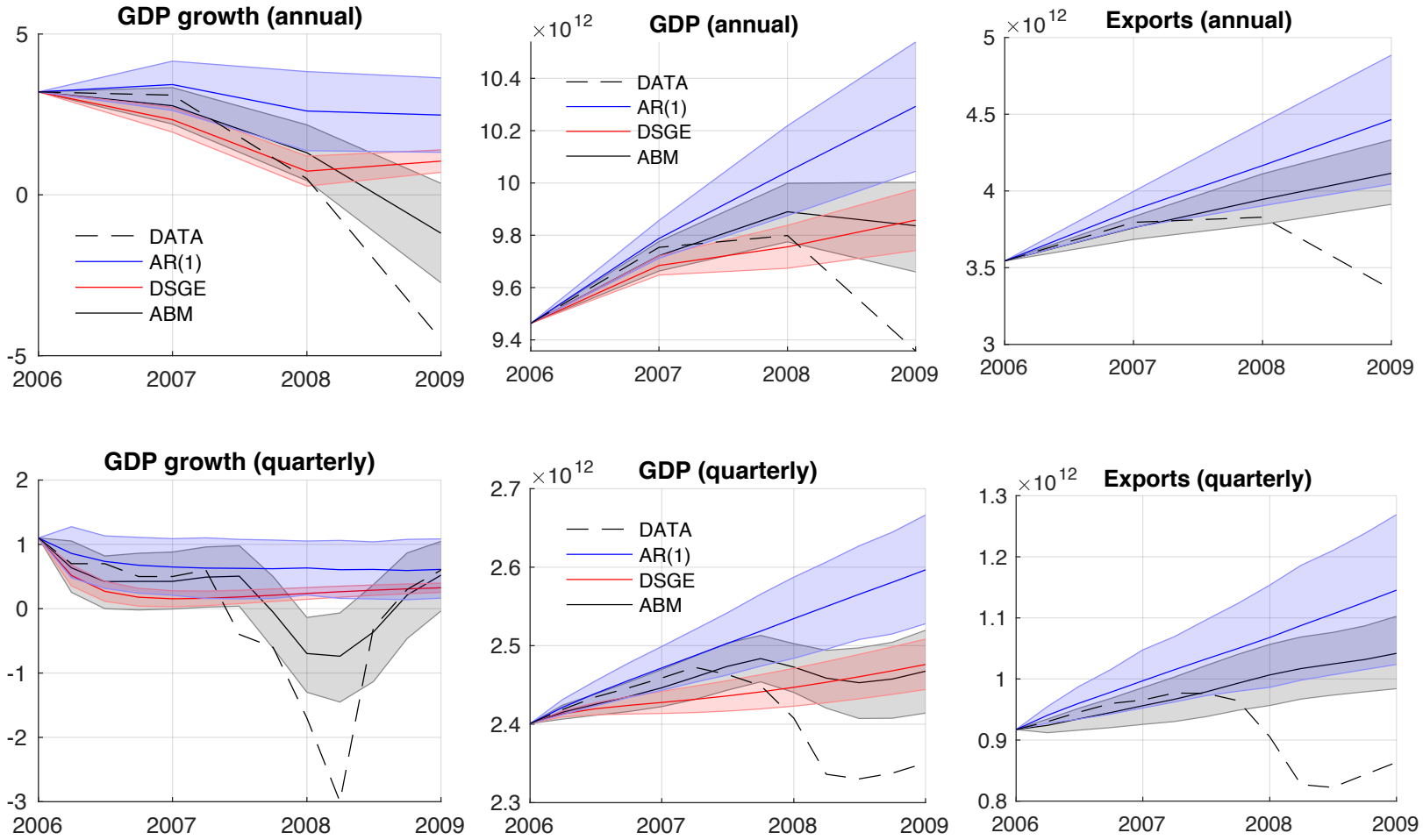


Figure: *Comparison of ABM simulations (black), AR(1) (blue), DSGE (red), and observed Eurostat data for the euro area (dashed line) for a forecast horizon of 12 quarters.*

Hommes, C. & Poledna, S. (2023)

Financial crisis of 2007-2008 in the euro area

with (forward-looking) expectations for a global downturn

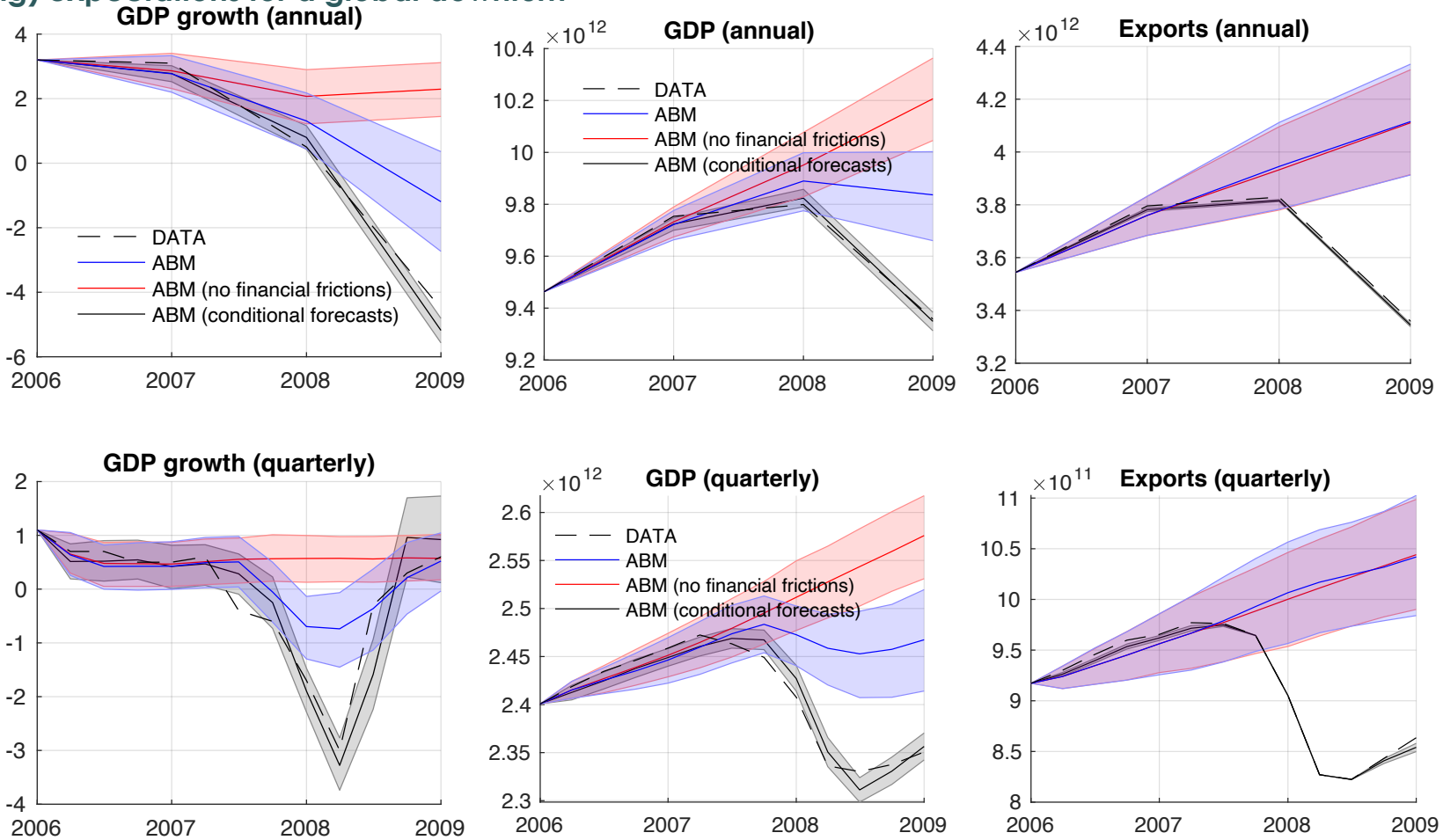
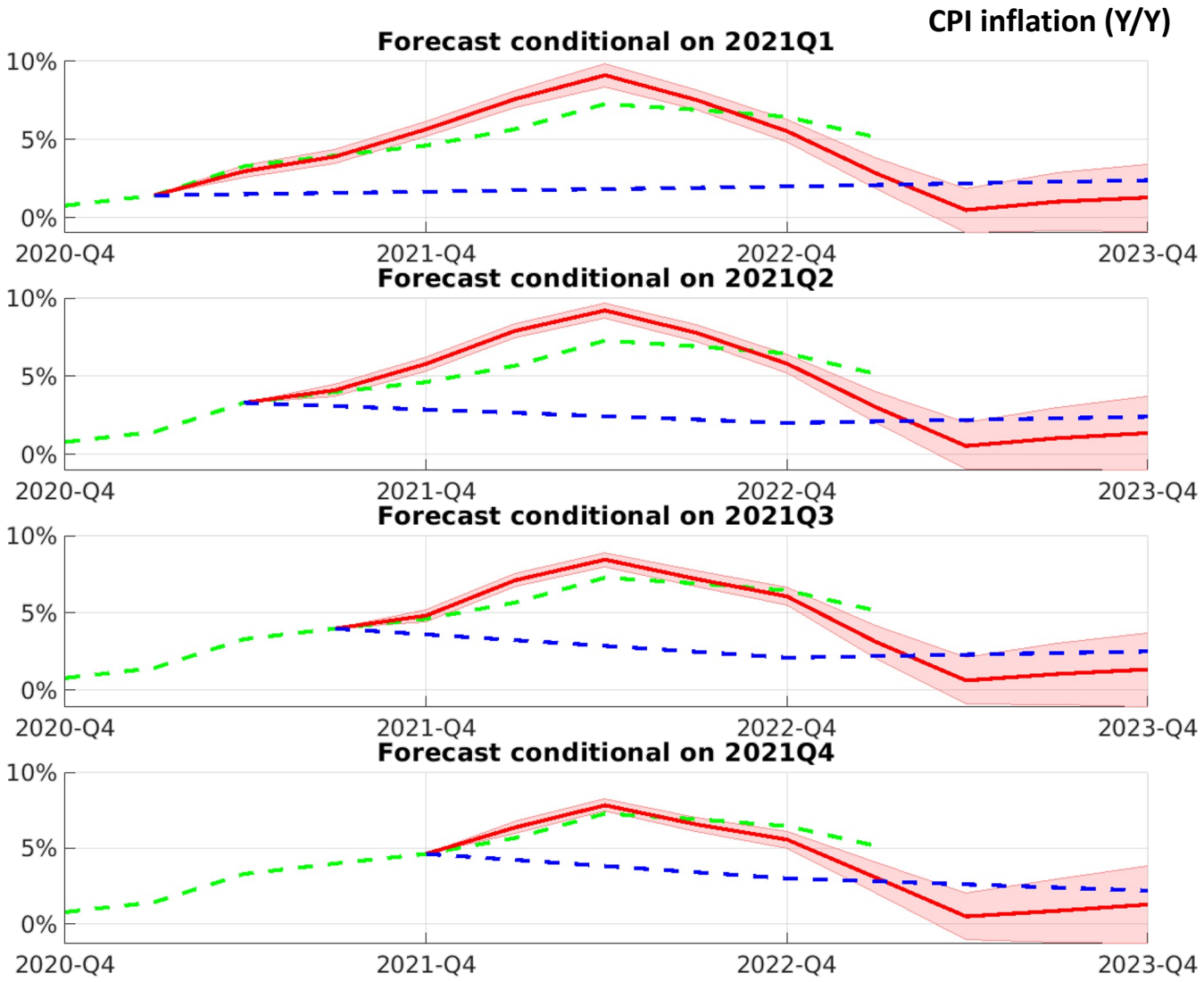


Figure: *Comparison of ABM simulations (blue), ABM without financial frictions (red), conditional forecasts (on exports) of the ABM (black), and observed Eurostat data for the euro area (dashed line) for a forecast horizon of 12 quarters.*

Hommes, C. & Poledna, S. (2023)

CANVAS: A Canadian Behavioral Agent-Based Model



Staff Working Paper/Document de travail du personnel—2022-51

Last updated: December 19, 2022

BANK OF CANADA
BANQUE DU CANADA

CANVAS: A Canadian Behavioral Agent-Based Model

by Cars Hommes,[1] Mario He,[2] Sebastian Poledna,[3] Melissa Siqueira[4] and Yang Zhang[2]

Hommes, C., Kozicki, S., Poledna, S., & Zhang, Y. (2025)

Hommes, C., He, M., Poledna, S., Siqueira, M., & Zhang, Y. (2024)

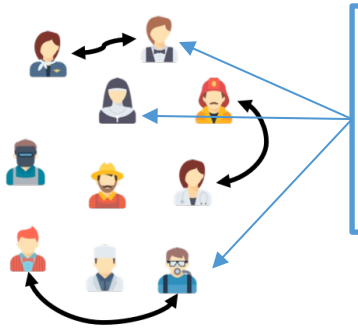
Economic and labor market impacts of migration

- We study an extreme yet still **realistic migration scenario** (similar to the 2015 Syrian refugee crisis, ~250k migrants in two years)
- Our focus is on **macroeconomic impacts** and detailed **labour market dynamics**
- We simulate the artificial Austrian economy at a scale of 1:1 with **detailed microdata** from Statistic Austria *Register-based Labour Market Career* (ERV) data

Register-based Labour Market Career (ERV)
Data on the employment history of each person in Austria from 2009 onwards (~4.1 mln. employees; ~20 mln. employment relationships)

- Unemployment rate…
- Wages…
- Social benefits…

…by economic sector and socio-economic status

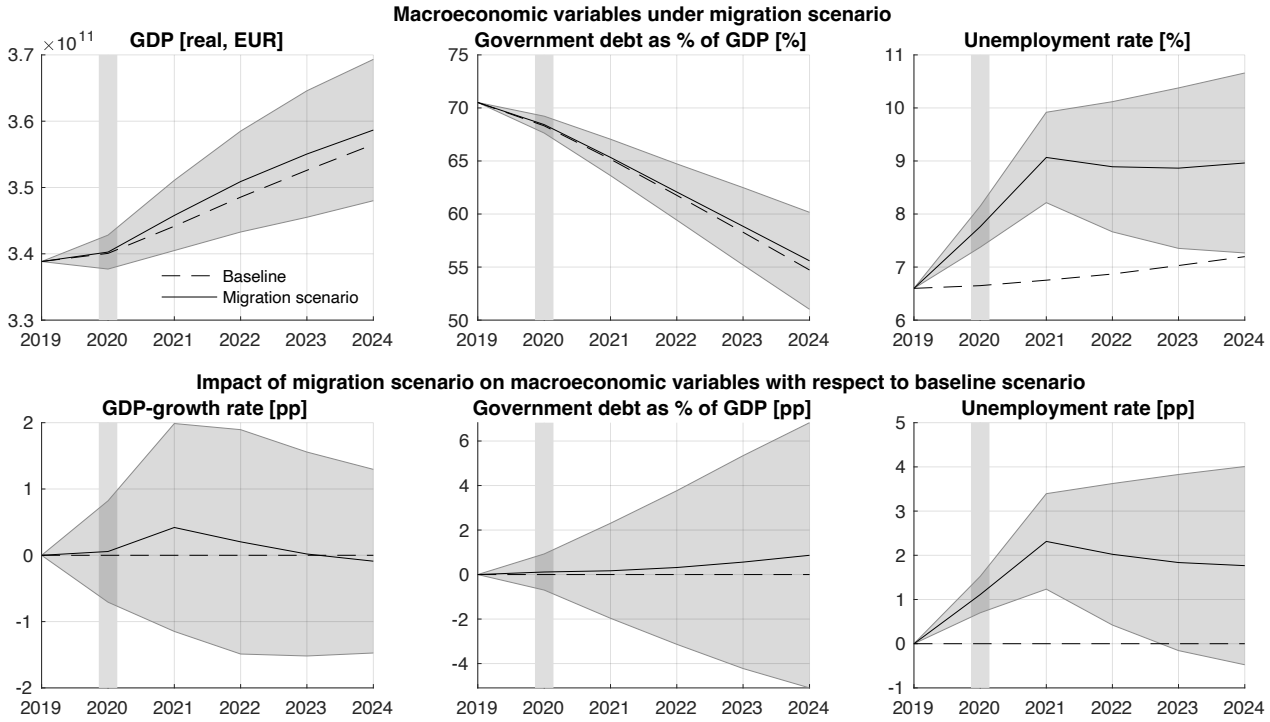


Gender, nationality, economic sector, current and previous employment status, etc.

Images sources: Tindoarchitect/Dreamstime, (Izquierdo et al., 2019)

Poledna, S., Strelkovskii, N., Conte, A., Goujon, A., Linnerooth-Bayer, J., Catalano, M., & Rovenskaya, E. (2024)

Economic and labor market impacts of migration



Nationality	Gender	Variable	0	1	2	3	4	5
NATIVES	MEN	u.r. (%)	5.20%	5.33%	5.59%	5.83%	6.10%	6.35%
		Δ u.r. (p.p)	+0.00%	+0.03%	+0.10%	+0.25%	+0.46%	+0.71%
		# U (units)	85350	87833	92680	97509	102824	107966
		Δ # U (units)	+0	+493	+1527	+3743	+7156	+11140
	WOMEN	u.r. (%)	5.21%	5.39%	5.73%	6.06%	6.37%	6.64%
		Δ u.r. (p.p)	+0.00%	+0.01%	+0.03%	+0.13%	+0.31%	+0.54%
		# U (units)	80615	83663	89854	95893	101781	107241
		Δ # U (units)	+0	+76	+300	+1588	+4266	+7671
EU	MEN	u.r. (%)	7.07%	6.80%	6.28%	5.92%	5.78%	5.77%
		Δ u.r. (p.p)	+0.00%	+0.09%	+0.30%	+0.52%	+0.74%	+0.96%
		# U (units)	14483	14219	13731	13504	13647	14028
		Δ # U (units)	+0	+129	+437	+785	+1238	+1721
	WOMEN	u.r. (%)	8.91%	8.91%	8.89%	8.87%	8.92%	9.01%
		Δ u.r. (p.p)	+0.00%	+0.04%	+0.14%	+0.34%	+0.59%	+0.87%
		# U (units)	18211	18404	18845	19343	19996	20739
		Δ # U (units)	+0	+49	+148	+399	+815	+1321
Other Countries	MEN	u.r. (%)	11.80%	11.51%	10.86%	10.23%	9.73%	9.36%
		Δ u.r. (p.p)	+0.00%	+0.09%	+0.34%	+0.67%	+1.02%	+1.36%
		# U (units)	28023	27450	26161	24912	23975	23309
		Δ # U (units)	+0	+198	+727	+1447	+2242	+3023
	WOMEN	u.r. (%)	14.34%	14.41%	14.53%	14.65%	14.80%	14.96%
		Δ u.r. (p.p)	+0.00%	+0.03%	+0.10%	+0.24%	+0.45%	+0.73%
		# U (units)	30149	30378	30865	31383	32003	32657
		Δ # U (units)	+0	+54	+144	+343	+726	+1244
Refugees	MEN	u.r. (%)	28.86%	25.29%	18.76%	13.81%	10.57%	8.42%
		Δ u.r. (p.p)	+0.00%	+35.66%	+45.87%	+38.82%	+31.86%	+26.04%
		# U (units)	11319	10162	7955	6199	5003	4183
		Δ # U (units)	+0	+41755	+91063	+78827	+66050	+55540
	WOMEN	u.r. (%)	32.47%	21.00%	9.14%	4.61%	2.89%	2.18%
		Δ u.r. (p.p)	+0.00%	+33.20%	+33.17%	+19.66%	+11.62%	+7.19%
		# U (units)	1795	1298	700	430	318	275
		Δ # U (units)	+0	+7290	+12977	+8401	+5493	+3823

u.r.: Unemployment rate in the baseline scenario; Δ u.r.: Difference in the unemployment rate (in p.p.) between the migration scenario and the baseline scenario; #U: Absolute number of unemployed persons in the baseline scenario; Δ#U: Difference in the absolute number of unemployed persons between the migration scenario and the baseline scenario

Poledna, S., Strelkovskii, N., Conte, A., Goujon, A., Linnerooth-Bayer, J., Catalano, M., & Rovenskaya, E. (2024)

Economic and labor market impacts of migration

Industry	Variable	0	1	2	3	4	5
A	u.r. (%)	8.19%	8.08%	8.26%	8.67%	9.21%	9.71%
	Δ u.r. (p.p)	+0.00%	+2.38%	+5.07%	+4.73%	+4.53%	+4.55%
	# U (units)	1791	1770	1831	1955	2112	2265
	Δ # U (units)	+0	+583	+1311	+1252	+1229	+1256
B	u.r. (%)	2.75%	2.76%	2.73%	2.83%	3.01%	3.12%
	Δ u.r. (p.p)	+0.00%	+0.02%	+0.10%	+0.18%	+0.29%	+0.43%
	# U (units)	167	172	179	191	206	216
	Δ # U (units)	+0	+2	+7	+13	+20	+31
C	u.r. (%)	3.40%	3.53%	3.71%	3.94%	4.24%	4.51%
	Δ u.r. (p.p)	+0.00%	+0.36%	+0.78%	+0.75%	+0.80%	+0.89%
	# U (units)	21669	22715	24448	26522	29033	31414
	Δ # U (units)	+0	+2442	+5431	+5421	+5917	+6663
D	u.r. (%)	1.40%	1.12%	0.81%	0.72%	0.70%	0.69%
	Δ u.r. (p.p)	+0.00%	+0.05%	+0.06%	+0.03%	+0.10%	+0.20%
	# U (units)	73	59	42	38	37	37
	Δ # U (units)	+0	+2	+3	+2	+6	+11
E	u.r. (%)	4.05%	4.20%	4.94%	5.86%	6.83%	7.79%
	Δ u.r. (p.p)	+0.00%	+0.61%	+1.13%	+0.80%	+0.83%	+1.08%
	# U (units)	637	663	790	958	1142	1331
	Δ # U (units)	+0	+101	+196	+146	+158	+210
F	u.r. (%)	5.17%	5.11%	4.98%	4.92%	4.97%	5.07%
	Δ u.r. (p.p)	+0.00%	+0.57%	+1.01%	+0.65%	+0.49%	+0.52%
	# U (units)	14768	14626	14371	14372	14676	15134
	Δ # U (units)	+0	+1738	+3176	+2127	+1658	+1789
G	u.r. (%)	6.54%	6.59%	6.71%	6.86%	7.05%	7.26%
	Δ u.r. (p.p)	+0.00%	+0.61%	+1.08%	+0.82%	+0.74%	+0.78%
	# U (units)	41306	41795	43050	44528	46361	48307
	Δ # U (units)	+0	+4198	+7853	+6272	+5808	+6125
H	u.r. (%)	6.07%	5.97%	5.71%	5.52%	5.50%	5.51%
	Δ u.r. (p.p)	+0.00%	+0.81%	+1.63%	+1.40%	+1.28%	+1.32%
	# U (units)	11780	11625	11230	11008	11119	11262
	Δ # U (units)	+0	+1695	+3505	+3060	+2850	+2944
I	u.r. (%)	18.31%	17.92%	17.04%	16.05%	15.12%	14.25%
	Δ u.r. (p.p)	+0.00%	+4.27%	+8.82%	+8.03%	+7.18%	+6.49%
	# U (units)	46739	45712	43345	40775	38376	36155
	Δ # U (units)	+0	+14089	+30914	+27608	+24183	+21409
K	u.r. (%)	3.88%	3.95%	4.29%	4.71%	5.19%	5.66%
	Δ u.r. (p.p)	+0.00%	+0.13%	+0.20%	+0.13%	+0.29%	+0.55%
	# U (units)	4324	4422	4854	5429	6080	6741
	Δ # U (units)	+0	+156	+251	+194	+403	+736

Industry	Variable	0	1	2	3	4	5
J	u.r. (%)	2.63%	2.83%	3.18%	3.51%	3.87%	4.19%
	Δ u.r. (p.p)	+0.00%	-+0.01%	-+0.15%	-+0.24%	-+0.19%	-+0.03%
	# U (units)	3087	3348	3815	4285	4795	5264
	Δ # U (units)	+0	-+13	-+169	-+274	-+207	+0
L	u.r. (%)	5.96%	5.78%	5.43%	5.13%	4.93%	4.78%
	Δ u.r. (p.p)	+0.00%	+0.25%	+0.23%	+0.08%	+0.11%	+0.24%
	# U (units)	2915	2830	2670	2535	2450	2391
	Δ # U (units)	+0	+132	+144	+69	+87	+155
M	u.r. (%)	4.62%	4.54%	4.54%	4.66%	4.91%	5.20%
	Δ u.r. (p.p)	+0.00%	+0.24%	+0.41%	+0.34%	+0.46%	+0.70%
	# U (units)	9586	9436	9525	9901	10559	11339
	Δ # U (units)	+0	+531	+942	+807	+1104	+1688
N	u.r. (%)	19.02%	18.41%	17.09%	15.85%	14.86%	14.09%
	Δ u.r. (p.p)	+0.00%	+4.91%	+10.13%	+9.11%	+8.05%	+7.22%
	# U (units)	52442	50577	46711	43221	40538	38516
	Δ # U (units)	+0	+17621	+38362	+33602	+28993	+25517
O	u.r. (%)	2.42%	3.07%	4.41%	5.62%	6.67%	7.62%
	Δ u.r. (p.p)	+0.00%	+0.08%	+0.26%	+0.33%	+0.45%	+0.59%
	# U (units)	16096	20652	30195	39264	47477	55139
	Δ # U (units)	+0	+587	+1887	+2426	+3432	+4581
P	u.r. (%)	4.45%	4.56%	4.73%	4.82%	4.83%	4.81%
	Δ u.r. (p.p)	+0.00%	+0.35%	+0.72%	+0.73%	+0.82%	+0.95%
	# U (units)	7781	8013	8399	8626	8718	8748
	Δ # U (units)	+0	+646	+1374	+1413	+1588	+1842
Q	u.r. (%)	8.05%	8.15%	8.32%	8.46%	8.57%	8.64%
	Δ u.r. (p.p)	+0.00%	+1.28%	+2.78%	+2.63%	+2.46%	+2.39%
	# U (units)	23866	24274	25051	25699	26283	26748
	Δ # U (units)	+0	+4250	+9562	+9149	+8675	+8460
R	u.r. (%)	9.72%	9.20%	8.13%	7.14%	6.34%	5.72%
	Δ u.r. (p.p)	+0.00%	+0.55%	+1.00%	+0.90%	+0.93%	+1.04%
	# U (units)	3877	3661	3224	2824	2511	2268
	Δ # U (units)	+0	+248	+463	+417	+425	+465
S	u.r. (%)	7.01%	7.00%	6.96%	6.88%	6.84%	6.83%
	Δ u.r. (p.p)	+0.00%	+0.94%	+1.84%	+1.56%	+1.40%	+1.34%
	# U (units)	7041	7056	7063	7044	7073	7123
	Δ # U (units)	+0	+1038	+2110	+1827	+1657	+1601
TOTAL	u.r. (%)	6.60%	6.65%	6.75%	6.86%	7.02%	7.19%
	Δ u.r. (p.p)	+0.00%	+1.12%	+2.31%	+2.02%	+1.83%	+1.76%
	# U (units)	269945	273406	280793	289173	299546	310399
	Δ # U (units)	+0	+50046	+107322	+95533	+87986	+85482

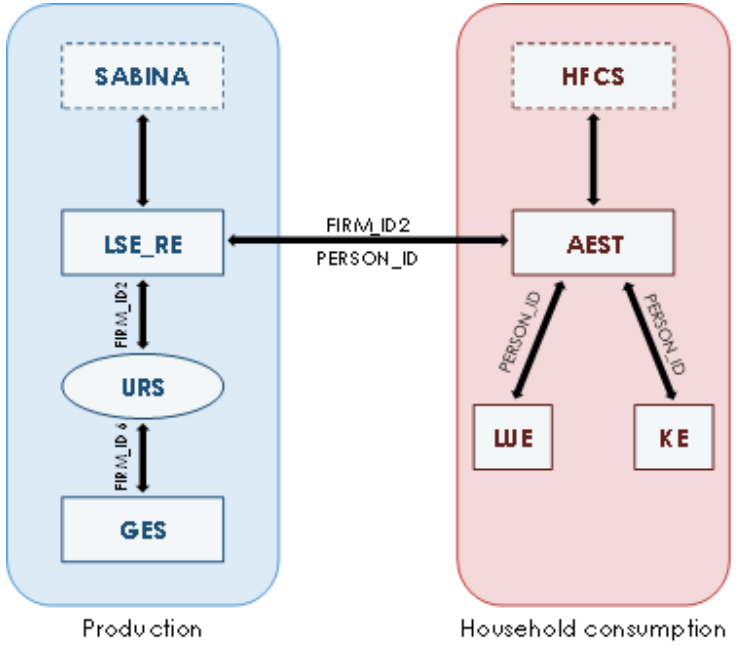
	Industry
A	Agriculture, Forestry and Fishing
B	Mining and Quarrying
C	Manufacturing
D	Electricity, Gas, Steam and Air Conditioning Supply
E	Water Supply; Sewerage, Waste Management and Remediation Activities
F	Construction
G	Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles
H	Transportation and Storage
I	Accommodation and Food Service Activities
J	Information and Communication
K	Financial and Insurance Activities
L	Real Estate Activities
M	Professional, Scientific and Technical Activities
N	Administrative and Support Service Activities
O	Public Administration and Defence; Compulsory Social Security
P	Education
Q	Human Health and Social Work Activities
R	Arts, Entertainment and Recreation
S	Other Service Activities
T	Activities of Households as Employers; Undifferentiated Goods and Services Producing Activities of Households for Own Use
U	Activities of Extraterritorial Organisations and Bodies

Poledna, S., Strelkovskii, N., Conte, A., Goujon, A., Linnerooth-Bayer, J., Catalano, M., & Rovenskaya, E. (2024)

A Digital Twin for Austria

Development of a highly granular macroeconomic ABM with registry data from the Austrian Micro Data Center (AMDC) and firm-level data (ORBIS/SABINA)

Realistic representation of heterogeneity in households and firms (e.g., gender, education, income, employment, ...)



- Household Finance and Consumption Survey (ECB: HFCS)
- Balance sheet data (Bureau van Dijk: SABINA)
- LSE RE – Structural Business Statistics (STAT: Leistungs- und Strukturstatistik - rechtliche Einheiten)
- URS – Statistical Business Register (STAT: Statistisches Unternehmensregister)
- GES – Material Input Statistics (STAT: Gütereinsatzstatistik)
- AEST REGZ – Register-Based Census (STAT: Abgestimmte Erwerbsstatistik und Registerzählung)
- LUE – Income Tax Statistics (STAT: Integrierte Lohn- und Einkommensteuerstatistik)
- KE – Household Budget Survey (STAT: Konsumerhebung 2019/20)

Two ongoing joint projects of WIFO, IIASA, and WU:

- Distributional implications of a high inflation, high interest rate environment (Data:Research:Austria, ÖAW)
- People-Centered Economic Modelling for Climate Policy (Vienna Science and Technology Fund WWTF)

Conclusion & Outlook

- **Macroeconomic ABM: A Cutting-Edge Modeling Technology**
  - Leverages microdata and benefits from rapid advances in computing
  - Well suited for policy analysis by capturing heterogeneity, non-linear interactions, and network effects
- **Broad Applications & International Reach**
  - Successfully applied to real-world crises (financial, pandemic, inflation, tariffs)
  - Adopted by central banks (e.g., Bank of Canada) and research institutes worldwide
- **Vienna: An Emerging Center for ABM Research**
  - Collaboration among WIFO, WU, IIASA, and also IHS and wiiw
  - Access to AMDC microdata supports large-scale simulations and deeper policy analysis
- **Looking Ahead**
  - Develop a "core" ABM framework, akin to the core DSGE model
  - Create a "Digital Twin" for Austria to enhance policy insights

Further reading

- Dawid, H. & Delli Gatti, D. (2018). *Agent-based macroeconomics*. Handbook of Computational Economics (Vol. 4), 63-156.
- Dawid, H. Delli Gatti, D. Fierro, L. E., & Poledna, S. (2024). Implications of Behavioral Rules in Agent-based Macroeconomics. Bielefeld Working Papers in Economics and Management No. 04-2024
- Hommes, C., He, M., Poledna, S., Siqueira, M., & Zhang, Y. (2024). CANVAS: A Canadian Behavioral Agent-Based Model. Journal of Economic Dynamics and Control, 104986.
- Hommes, C. H. & Poledna (2023). Analyzing and forecasting economic crises with an agent-based model of the euro area. Available at SSRN 4381261.
- Poledna, S., Strelkovskii, N., Conte, A., Goujon, A., Linnerooth-Bayer, J., Catalano, M., & Rovenskaya, E. (2024). Economic and labour market impacts of migration in Austria: an agent-based modelling approach. Comparative Migration Studies, 12(1), 18.
- Poledna, S., Miess, M. G., Hommes, C., & Rabitsch, K. (2023). Economic forecasting with an agent-based model. European Economic Review, 151, 104306.
- Poledna, S., Rovenskaya, E., Cuaresma, J. C., Kaniovski, S., & Miess, M. G. (2020). Recovery of the Austrian economy following the COVID-19 crisis can take up to three years. IIASA Policy Brief# 26.

Appendix: Model

Agents in the Model

Agents:

- Non-financial corporations (firm sector), limited companies and self-employed
- Financial corporations (banking sector), one representative bank
- Households (individual persons)
  - Employed (active on labor market)
  - Unemployed (involuntarily idle)
  - Investor (own firms)
  - Inactive households (not active on labor market, receive social benefits)
- General government
- Central Bank

Model: Non-financial corporations (firm sector)

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

Output (P.1) → part of which results in realized sales:
+ P_i Q_i where P_i is the 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)

Firms: Expectations

Agents' expectations are modelled by a parsimonious form of **adaptive learning** where agents act as econometricians and learn the optimal (consistent with the sample mean and first-order autocorrelation) parameters of simple AR rules following Hommes and Zhu (2014).

Expectations on GDP growth and inflation are formed using AR(1):

$$\gamma^e(t) = \alpha^\gamma(t-1)\gamma(t-1) + \beta^\gamma(t-1) + \epsilon^\gamma(t)$$

$$\pi^e(t) = \alpha^\pi(t-1)\pi(t-1) + \beta^\pi(t-1) + \epsilon^\pi(t)$$

where $\alpha^\gamma(t-1)$, $\alpha^\pi(t-1)$, $\beta^\gamma(t-1)$, $\beta^\pi(t-1)$, are coefficients re-estimated every period and $\epsilon^\gamma(t)$, and $\epsilon^\pi(t)$ are random shocks.

Firms: Supply Choice & Pricing

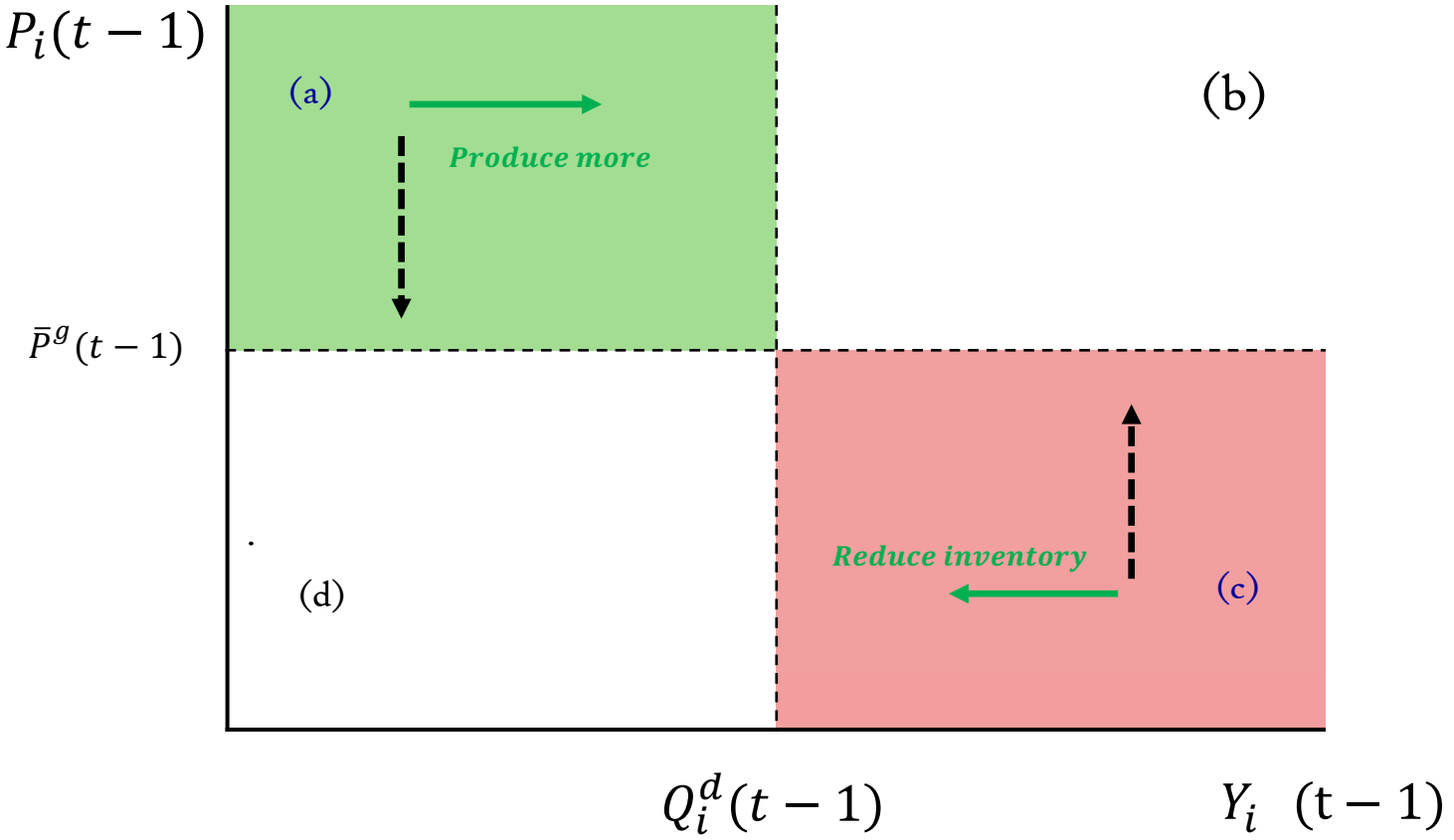
Supply choice: Firms change supply based on expectations of economic growth $\gamma^e(t)$ and perceived local market conditions using two indicators: the level of excess supply, which is the difference between the previous period's supply $Y_i\ \ (t-1)$ and demand $Q_i^d(t-1)$, and the deviation of the firm's own price $P_i(t-1)$ from the average price of firms' producing the same good, $\bar{P}^g(t-1)$:

$$Q_i^S(t) = Y_i\ \ (t-1)\,(1+\gamma^e(t))\,(1+\gamma_i^d(t))$$

Price-setting includes **three components** of inflation (*built-in inflation, demand-pull inflation, and cost-push inflation*):

$$P_i(t) = P_i(t-1)\cdot \underbrace{(1+\pi_i^c(t))}_{cost-push\ inflation} \cdot \underbrace{(1+\pi_i^d(t))}_{demand-pull\ inflation} \cdot \underbrace{(1+\pi^e(t))}_{built-in\ inflation}$$

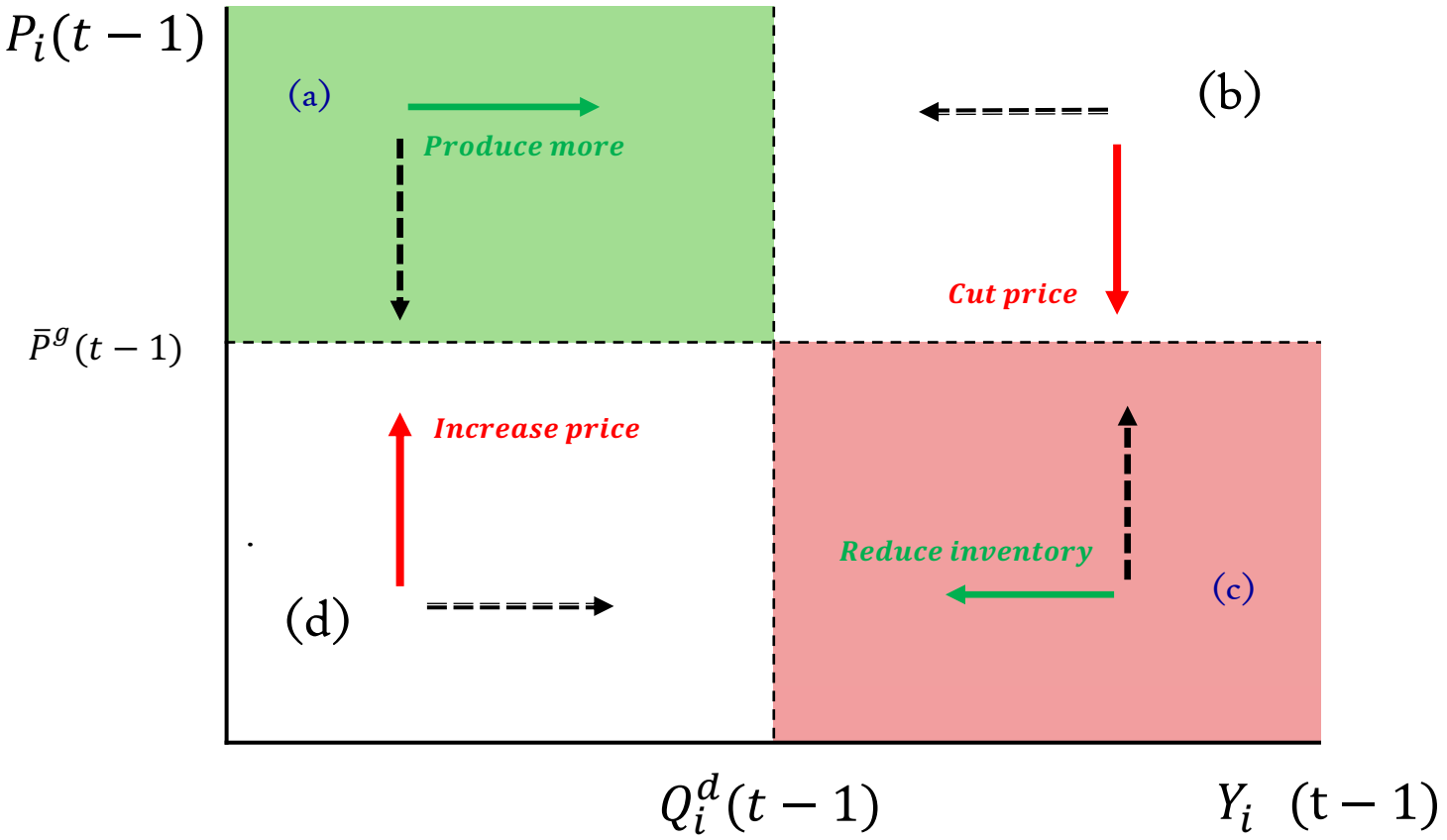
Firms: Supply Choice & Pricing



$$\gamma_i^d(t) = \begin{cases} positive, & if \text{ optimistic about demand despite higher price than average} \\ negative, & if \text{ positive inventory and price is already competitive} \end{cases}$$

Delli Gatti, D. et al. (2011). Macroeconomics from the bottom-up. Springer Milan.

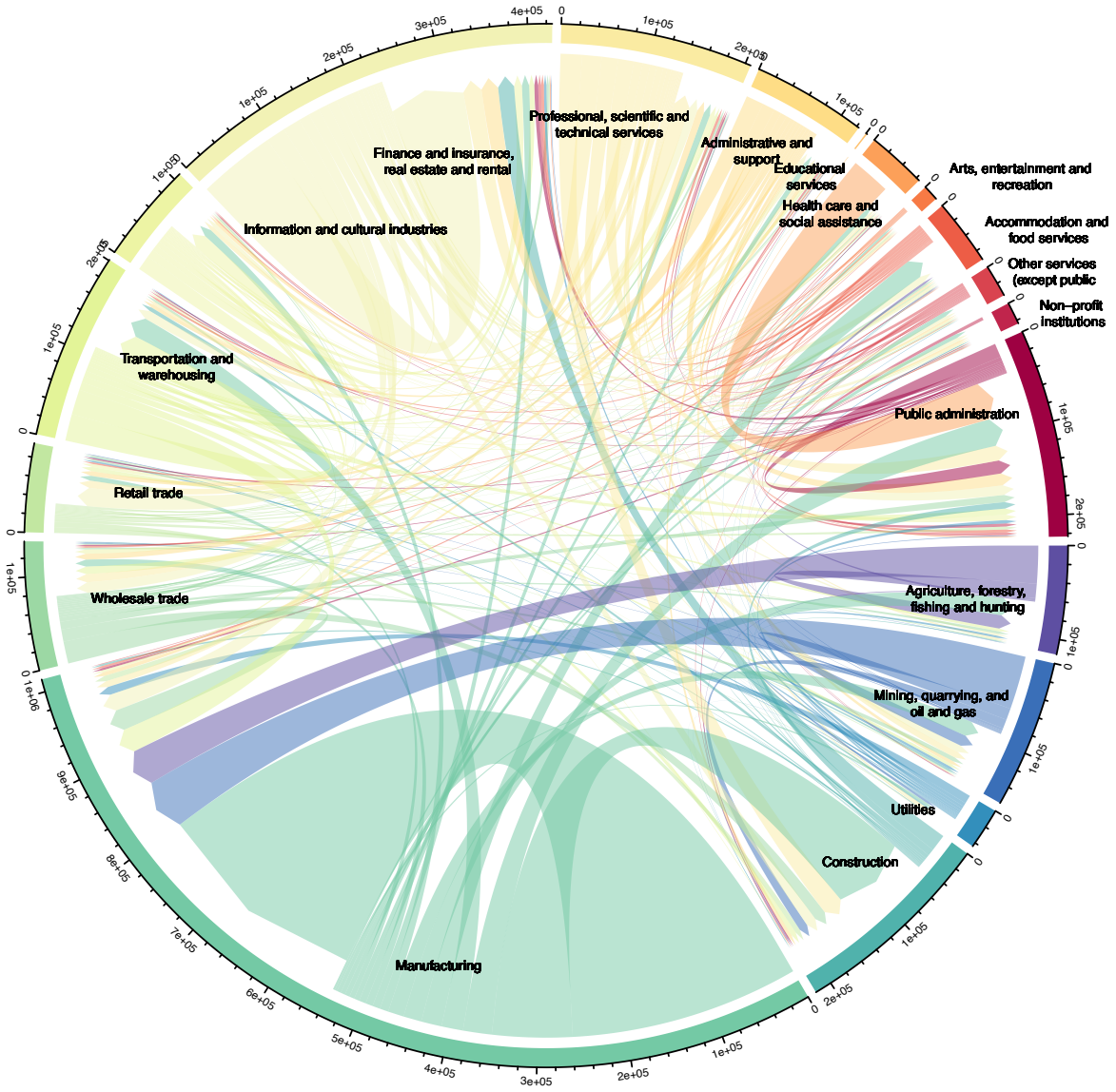
Firms: Supply Choice & Pricing



$$\pi_i^d(t) = \begin{cases} positive, & if \text{ optimistic about demand and price is competitive} \\ negative, & if \text{ positive inventory but charged higher price than average} \end{cases}$$

Delli Gatti, D. et al. (2011). Macroeconomics from the bottom-up. Springer Milan.

Firms: Output



Firm i produces $Y_i(t)$ with **Leontief technology** using labour $N_i(t)$, intermediate inputs $M_i(t)$ and capital stock $K_i(t-1)$:

$$Y_i(t) = min(Q_i^s(t), \alpha_i N_i(t), \beta_i M_i(t), \kappa_i K_i(t-1))$$

α_i, β_i and κ_i: productivity coefficients, a_{sg} technologically determined input coefficients

$$\pi_i^c(t) = \underbrace{\frac{(1+\tau^{SIF})\bar{w}_i}{\bar{\alpha}_i}\left(\frac{\bar{P}^{HH}(t-1)}{P_i(t-1)}-1\right)}_{\boldsymbol{Wage}} + \underbrace{\frac{1}{\beta_i}\left(\frac{\sum_g \boldsymbol{\alpha_{sg}}\bar{P}^g(t-1)}{P_i(t-1)}-1\right)}_{\boldsymbol{Production\ Inputs}} + \underbrace{\frac{\delta_i}{\kappa_i}\left(\frac{\bar{P}^{CF}(t-1)}{P_i(t-1)}-1\right)}_{\boldsymbol{Financing\ Cost}}$$

Firms: Demand & Sales

Demand: each firm i experiences demand $Q_i^d(t)$ from consumers. The level of demand will be determined by consumers only after the firm has set its price and carried out production $Y_i(t)$ and is subject to the search and matching mechanism specifying the visiting consumers of firm i :

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

where $S_i\ (t-1)$ is the inventory of finished goods.

Sales $Q_i\ (t)$ are then the realized demand dependent on the supply available from firm i after the production process has taken place:

$$Q_i\ (t) = min\big(S_i\ (t-1) + Y_i(t), Q_i^d(t)\big)$$

Firm: external funding & investment

If internal financial resources $D_i\ (t-1)$ of a firm are not enough to finance its expected expenditures $\Delta D_i^e(t)$, the firm will ask for a bank loan to cover its financing gap,

$$\Delta L_i^d(t) = \Delta D_i^e(t) - D_i\ (t-1)$$

The availability of credit depends on the financial condition of the firm and will be limited by the expected market value of the collateral and the total outstanding debt,

$$\Delta L_i\ (t) \leq \zeta^{LTV}(1+\pi^e\ (t))\bar{P}^{CF}(t-1)K_i^e(t) - (1-\theta)L_i\ (t-1)$$

If firm i has a funding gap, i.e. the difference between requested and granted external funding $(\Delta L_i^d(t) - \Delta L_i\ (t))$, the firms' investment is reduced,

$$I_i^d(t) = \frac{\delta_i Q_i^s(t)}{\kappa_i} - \frac{\Delta L_i^d(t) - \Delta L_i\ (t)}{\left(1+\pi^e\ (t)\right)\bar{P}^{CF}(t-1)}$$

where δ_i is the firm's capital depreciation rate. Therefore, a fall in asset prices results in a deterioration of the ability of firms to borrow, which has a negative impact on their investment.

Model: Households (individual persons)

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)

Households: Income

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):

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

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**:

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

and on **investment**:

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

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.

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

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

Model: General Government

General Government: Economic activities

The 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, and 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)

General Government: Revenues

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

General Government: Deficit & Debt

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

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

The **government debt** is determined by the year-to-year deficits/surpluses of the government sector: $L^G(t) = L^G(t-1) + \Pi^G(t)$

Model: Financial corporations (banking sector)

Banking sector

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

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

$$\frac{L_i(t)}{\bar{P}^{CF}(t-1)K_i\ (t)} \leq \zeta^{LTV}$$

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:

$$r(t) = \bar{r}(t) + \mu$$

The Central Bank

The central bank **sets the policy rate** $\bar{r}(t)$ based on implicit inflation and growth targets, **provides liquidity** to the banking system (advances to the bank), and takes deposits from the bank in the form of reserves deposited at the central bank.

The policy rate is determined by an augmented Taylor rule, where the central bank agent learns the optimal parameters. Following Blattner and Margaritov (2010), we include forecasted quarter-over-quarter inflation and real GDP growth in the reaction function:

$$\bar{r}(t) = \rho(t-1)\bar{r}(t-1) + (1-\rho(t-1))(r^*(t-1) + \pi^* + \xi^{\pi}(t-1)(\pi^e(t) - \pi^*) + \xi^{\gamma}(t-1)\gamma^e(t))$$

where $\rho(t-1)$ is the interest rate smoothing parameter that reflects the gradual adjustment to the policy rate, $r^*(t-1)$ is the real equilibrium interest rate, π^* is the inflation target, $\xi^{\pi}(t-1)$ is the policy parameter on inflation deviations from the target, and $\xi^{\gamma}(t-1)$ is the weight on the forecasted real GDP growth rate.

Exports, Imports, Government Consumption

These economic aggregates are either assumed to be exogenously given from data (conditional forecasts) or to follow autoregressive (AR) processes due to the assumption of a small open economy setting.

Imports $Y^I(t)$, exports $C^E(t)$ and government consumption $C^G(\mathrm{t})$ (all real and in log levels) follow AR(1) processes:

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

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

$$C^G(\mathrm{t}) = \alpha^G C^G(t-1) + \beta^G + \epsilon^G(t)$$

Key modeling choices and mechanisms of the ABM

- includes **all sectors** (financial, non-financial, households, a general government) populated with a large number of **heterogenous agents** calibrated to census and survey (LFS) data
- includes a **complete GDP identity** with *all transactions* in products, non-financial assets, and distributive transactions calibrated to national accounting data
- rational expectations are relaxed with **adaptive learning** (Hommes and Zhu, 2014)
- includes a **multi-sector production network** calibrated to input-output tables
- has **decentralized markets**, which allows for **trade frictions**
- incorporates **financial frictions** with a **financial accelerator** and **debt-financed investment** (Bernanke, Gertler, & Gilchrist 1996)
- allows **non-linear responses**, which may be underestimated by linearized DSGE models (Lindé, 2018), and for the possibility of **endogenous economic crises without exogenous shocks**
- model is **validated** based on the comparison of its **forecast performance** (out-of-sample prediction) with that of econometric and DSGE models

Complete GDP identity

$$
\begin{aligned}
GDP(t) = & \underbrace{\sum_i \tau_i^{\mathrm{Y}} P_i(t) Y_i(t) + \sum_h \tau^{\mathrm{VAT}} C_h(t) + \sum_h \tau^{\mathrm{CF}} I_h(t) + \sum_j \tau^{\mathrm{G}} C_j(t) + \sum_l \tau^{\mathrm{EXPORT}} C_l(t)}_{\text{Taxes on products}} \\
& + \underbrace{\sum_i (1-\tau_i^{\mathrm{Y}}) P_i(t) Y_i(t)}_{\text{Total sales of goods and services}} - \underbrace{\sum_i \frac{1}{\beta_i} \bar{P}_i(t) Y_i(t)}_{\text{Intermediate inputs}} \quad \text{(Production approach)} \\
= & \underbrace{\sum_h (1+\tau^{\mathrm{VAT}}) C_h(t)}_{\text{Household consumption}} + \underbrace{\sum_j (1+\tau^{\mathrm{G}}) C_j(t)}_{\text{Government consumption}} + \underbrace{\sum_h (1+\tau^{\mathrm{CF}}) I_h(t) + \sum_i P_i^{\mathrm{CF}}(t) I_i(t)}_{\text{Gross fixed capital formation}} \\
& + \underbrace{\sum_i P_i(t)(Y_i(t) - Q_i(t)) + \bar{P}_i(t) \left(\Delta M_i(t) - \frac{1}{\beta_i} Y_i(t) \right)}_{\text{Changes in inventories}} \\
& + \underbrace{\sum_l (1+\tau^{\mathrm{EXPORT}}) C_l(t)}_{\text{Exports}} - \underbrace{\sum_m P_m(t) Q_m(t))}_{\text{Imports}} \quad \text{(Expenditure approach)} \\
= & \underbrace{\sum_i \tau_i^{\mathrm{Y}} P_i(t) Y_i(t) + \sum_h \tau^{\mathrm{VAT}} C_h(t) + \sum_h \tau^{\mathrm{CF}} I_h(t) + \sum_j \tau^{\mathrm{G}} C_j(t) + \sum_l \tau^{\mathrm{EXPORT}} C_l(t)}_{\text{Taxes on products}} \\
& + \underbrace{\sum_i P_i(t) Y_i(t) - (1+\tau^{\mathrm{SIF}}) \bar{P}^{\mathrm{HH}}(t) N_i(t) w_i(t) - \frac{1}{\beta_i} \bar{P}_i(t) Y_i(t) - \tau_i^{\mathrm{Y}} P_i(t) Y_i(t) - \tau_i^{\mathrm{K}} P_i(t) Y_i(t)}_{\text{Gross operating surplus and mixed income}} \\
& + \underbrace{\sum_i (1+\tau^{\mathrm{SIF}}) \bar{P}^{\mathrm{HH}}(t) N_i(t) w_i(t)}_{\text{Compensation of employees}} + \underbrace{\sum_i \tau_i^{\mathrm{K}} P_i(t) Y_i(t)}_{\text{Net taxes on production}} \quad \text{(Income approach)}
\end{aligned}
$$

Calibration

Calibration

All parameters are calibrated to micro and macro data such that there is **no burn-in period** that has to be disregarded.

Data sources include national accounts, input-output tables, government statistics, demography data, and firm-level data.

Name	Code
Population by current activity status, NACE Rev. 2 activity and NUTS 2 region	cens_11an_r2
Business demography by legal form (from 2004 onwards, NACE Rev. 2)	bd_9ac_l_form_r2
Symmetric input-output table at basic prices (product by product)	naio_10_cp1700
Cross-classification of fixed assets by industry and by asset (stocks)	nama_10_nfa_st
Government revenue, expenditure and main aggregates	gov_10a_main
General government expenditure by function (COFOG)	gov_10a_exp
Quarterly non-financial accounts for general government	gov_10q_ggnfa
Quarterly government debt	gov_10q_ggdebt
Financial balance sheets	nasq_10_f_bs
Non-financial transactions (annually)	nasa_10_nf_tr
Non-financial transactions (quarterly)	nasq_10_nf_tr
GDP and main components (output, expenditure and income)	namq_10_gdp
Money market interest rates - quarterly data	irt_st_q

Table: Eurostat data tables used.

Parameters

Parameter	Description	Value	Source
G/S	Number of products/industries	62	census data, business demography data
H^{act}	Number of economically active persons	4729215	
H^{inact}	Number of economically inactive persons	4130385	
J	Number of government entities	152820	
L	Number of foreign consumers	305639	
I_s	Number of firms/investors in the s^{th} industry	see Online Appendix D	
$\bar{\alpha}_i$	Average productivity of labour of the i^{th} firm	parameters are firm/sector specific	input-output tables
κ_i	Productivity of capital of the i^{th} firm		
β_i	Productivity of intermediate consumption of the i^{th} firm		
δ_i	Depreciation rate for capital of the i^{th} firm		
$\bar{w}_i$	Average wage rate of firm i		
a_{sg}	Technology coefficient of the g^{th} product in the s^{th} industry		
b_g^{CF}	Capital formation coefficient of the g^{th} product (firm investment)		
b_g^{CFH}	Household investment coefficient of the g^{th} product		
b_g^{HH}	Consumption coefficient of the g^{th} product of households		
c_g^{G}	Consumption of the g^{th} product of the government in mln. Euro		
c_g^{E}	Exports of the g^{th} product in mln. Euro		
c_g^{I}	Imports of the g^{th} product in mln. Euro		
τ_i^{Y}	Net tax rate on products of the i^{th} firm		
τ_i^{K}	Net tax rate on production of the i^{th} firm		
τ^{INC}	Income tax rate	0.2134	government statistics, sector accounts
τ^{FIRM}	Corporate tax rate	0.0762	
τ^{VAT}	Value-added tax rate	0.1529	
τ^{SIF}	Social insurance rate (employers' contributions)	0.2122	
τ^{SIW}	Social insurance rate (employees' contributions)	0.1711	
τ^{EXPORT}	Export tax rate	0.0029	
τ^{CF}	Tax rate on capital formation	0.0876	
τ^{G}	Tax rate on government consumption	0.0091	
r^{G}	Interest rate on government bonds	0.0091	
μ	Risk premium on policy rate	0.0293	
ψ	Fraction of income devoted to consumption	0.9394	
ψ^{H}	Fraction of income devoted to investment in housing	0.0736	
θ^{DIV}	Dividend payout ratio	0.7768	
θ^{UB}	Unemployment benefit replacement rate	0.3586	Basel III, ECB statutes, banking practices, literature
θ	Rate of instalment on debt	0.05	
ζ	Banks' capital ratio	0.03	
ζ^{LTV}	Loan-to-value (LTV) ratio	0.6	
ζ^{b}	Loan-to-capital ratio for new firms after bankruptcy	0.5	
π^*	Inflation target of the monetary authority	0.005	

Table: Model parameters for the Austrian economy for 2010:Q4.

Initial conditions

Initial condition	Description	Value	Source
$P_i(0)$	Initial price of the i^{th} firm		
$Y_i(0)/Q_i^{\text{d}}(0)$	Initial production/demand of the i^{th} firm (in mln. Euro)		
$K_i(0)$	Initial capital of the i^{th} firm (in mln. Euro)		
$M_i(0)$	Initial stocks of raw materials, consumables, supplies of the i^{th} firm (in mln. Euro)		
$S_i(0)$	Initial stocks of finished goods of the i^{th} firm (in mln. Euro)		
$N_i(0)$	Initial number of employees of the i^{th} firm		
$D_i(0)$	Initial liquidity (deposits) of the i^{th} firm (in mln. Euro)		
$L_i(0)$	Initial debt of the i^{th} firm (in mln. Euro)		
$\Pi_i(0)$	Initial profits of the i^{th} firm (in mln. Euro)		
$D_h(0)$	Initial personal assets (deposits) of the h^{th} household (in mln. Euro)	-	
$K_h(0)$	Initial household capital (in mln. Euro)	-	
$w_h(0)$	Initial wage of the h^{th} household (in mln. Euro)	-	
$sb^{\text{inact}}(0)$	Initial pension/social benefits in mln. Euro	0.0022	
$sb^{\text{other}}(0)$	Initial social benefits received by all households in mln. Euro	0.0007	
$L^{\text{G}}(0)$	Initial government debt (in mln. Euro)	243871.1	
$\Pi_k(0)$	Initial banks' profits (in mln. Euro)	6516.2	
$E_k(0)$	Initial banks' equity (in mln. Euro)	97802.3	
$E^{\text{CB}}(0)$	Initial central banks' equity (in mln. Euro)	115947.6	
$D^{\text{RoW}}(0)$	Initial net creditor/debtor position of the national economy to RoW (in mln. Euro)	0	

firm level

sector accounts

sector accounts, government statistics

Table: Initial conditions for the Austrian economy for 2010:Q4.

Forecast performance

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 an 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 behaviour of agents
  - but for methodological reasons are restricted to smaller models with fewer variables than statistical models
- Agent-based models (ABMs)
  - combine advantages from large-scale statistical models and models derived from economic 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

Out-of-sample forecast performance in comparison to VAR for Austria

	GDP	Inflation	Government consumption	Exports	Imports	GDP EA	Inflation EA	Euribor
VAR(1)	*RMSE-statistic for different forecast horizons*							
1q	0.45	0.33	0.66	1.53	1.66	0.41	0.17	0.05
2q	0.82	0.3	0.67	2.83	2.66	0.79	0.15	0.08
4q	1.78	0.28	1	6.18	5.67	1.85	0.16	0.18
8q	4.06	0.28	1.61	13.46	11.96	4.08	0.18	0.42
12q	5.83	0.25	2.1	18.93	16.08	5.36	0.19	0.57
ABM	*Percentage improvements (+) or losses (-) relative to VAR(1) model*							
1q	-13 (0.36)	9.8 (0.21)	-14.1 (0.31)	10 (0.45)	7.5 (0.54)	-1.1 (0.94)	11.5 (0.12)	25.6 (0.16)
2q	4.3 (0.82)	7 (0.02**)	-14.5 (0.06*)	28.8 (0.04**)	16.8 (0.24)	2.6 (0.90)	-4.7 (0.64)	17.7 (0.35)
4q	25.6 (0.40)	0.1 (0.99)	3.6 (0.71)	47.4 (0.06*)	35.6 (0.12)	19.8 (0.60)	-4.8 (0.59)	37.7 (0.00***)
8q	46 (0.39)	-0.4 (0.92)	15.9 (0.13)	60.5 (0.16)	50.3 (0.23)	32.1 (0.63)	5.3 (0.58)	62.5 (0.02**)
12q	49.2 (0.50)	-0.5 (0.90)	13.4 (0.49)	62.2 (0.26)	48.1 (0.37)	25 (0.79)	5.8 (0.14)	64.2 (0.01**)

Table: RMSE-statistic for main aggregates from ABM simulations in comparison to a VAR(1) model for the forecast period from 2010:Q2-2019:Q4 for Austria.

Poledna, S., Miess, M. G., Hommes, C., & Rabitsch, K. (2023)

Comparison to DSGE models

As a comparison, we use the benchmark model of Smets and Wouters (2007) and the main DSGE model of the Bank of Canada ToTEM III.

ToTEM III is a large-scale, multi-sector, small-open-economy model with many shocks:

- Imperfectly competitive finished-goods sector for consumption, investment, government and non-commodity exports
- Small degree of nominal rigidity combined with firm-specific capital services
- Separate commodity-producing sector featuring perfect competition and flexible prices
- Commodities are used in the production of finished goods or are exported

Out-of-sample forecast performance in comparison to VAR and DSGE model for Canada

	GDP	Inflation	Consumption	Investment	Exports	Imports
VAR(1)	*RMSE-statistic for different forecast horizons*					
1q	0.48	0.73	0.33	1.54	2.17	1.8
2q	0.76	0.68	0.54	2.7	2.98	2.68
4q	1.24	0.65	1.01	5.19	3.53	4.55
8q	1.9	0.69	1.66	9.95	4.57	9.22
12q	2.24	0.71	1.98	15.14	4.65	13.83
ToTEM (III)	*Percentage gains (+) or losses (-) relative to VAR(1) model*					
1q	-27.2 (0.09)	14.4 (0.07)	-49.2 (0.00)	-18.8 (0.03)	14.9 (0.05)	24.2 (0.00)
2q	-56 (0.01)	7.3 (0.09)	-77.5 (0.00)	-28.7 (0.02)	20.4 (0.16)	27.6 (0.01)
4q	-73.4 (0.00)	1.9 (0.71)	-76.7 (0.02)	-16.8 (0.15)	6.8 (0.67)	30.1 (0.02)
8q	-58.5 (0.03)	8 (0.14)	-56.6 (0.18)	15.9 (0.50)	8.7 (0.78)	48 (0.00)
12q	-33.8 (0.29)	6.4 (0.23)	-39.2 (0.07)	41.5 (0.01)	24.7 (0.19)	64.9 (0.03)
CAN-ABM	*Percentage gains (+) or losses (-) relative to VAR(1) model*					
1q	0.6 (0.93)	10.1 (0.07)	-51.5 (0.01)	5.4 (0.49)	-0.7 (0.89)	13.5 (0.20)
2q	4 (0.46)	-0.6 (0.84)	-67.8 (0.02)	13.3 (0.02)	0.8 (0.90)	21.6 (0.07)
4q	17.2 (0.02)	-5.3 (0.27)	-25.3 (0.43)	23.6 (0.08)	-6.1 (0.36)	42.3 (0.02)
8q	20.6 (0.04)	-6.4 (0.19)	7.7 (0.85)	33.5 (0.09)	-15.5 (0.31)	65.9 (0.01)
12q	33.4 (0.00)	-2.4 (0.58)	31.8 (0.67)	43.3 (0.00)	-38.5 (0.17)	79.6 (0.05)

Note: RMSE-statistic for main aggregates from ABM simulations in comparison to a VAR(1) and the main DSGE model of the Bank of Canada (ToTEM III) for the forecast period from 2010:Q2-2019:Q4 for Canada.

Hommes, C., He, M., Poledna, S., Siqueira, M., & Zhang, Y. (2022)

Out-of-sample forecast performance in comparison to VAR for the euro area

	GDP	Inflation	Euribor	Government consumption	Exports
VAR(1)	*RMSE-statistic for different forecast horizons*				
1q	0.74	0.21	0.09	0.31	2.1
2q	1.63	0.21	0.18	0.48	4.88
4q	3.59	0.23	0.39	0.88	10.73
8q	6.98	0.25	0.71	1.75	20.46
12q	7.72	0.22	0.7	2.61	22.47
ABM	*Percentage gains (+) or losses (-) relative to VAR(1) model*				
1q	3.1 (0.31)	8.5 (0.10)	1.4 (0.47)	-98.4 (0.90)	-3.4 (0.54)
2q	11 (0.11)	4.6 (0.29)	9.1 (0.27)	-64.2 (0.85)	18.5 (0.24)
4q	30.4 (0.12)	9.6 (0.18)	26.1 (0.12)	-9 (0.82)	36.4 (0.13)
8q	45.3 (0.13)	14.6 (0.15)	46.7 (0.09)	-17.3 (0.82)	52.4 (0.11)
12q	38.1 (0.14)	9.1 (0.12)	42.5 (0.03)	-19.8 (0.84)	52.8 (0.07)
ABM (with financial frictions)	*Percentage gains (+) or losses (-) relative to VAR(1) model*				
1q	8.1 (0.40)	3.1 (0.43)	-2.3 (0.53)	-18.8 (0.96)	-4.5 (0.56)
2q	21.2 (0.21)	11.6 (0.26)	10.8 (0.30)	-4.6 (0.73)	18.6 (0.24)
4q	35.1 (0.14)	3.1 (0.33)	32.3 (0.13)	-7 (0.86)	36.6 (0.13)
8q	53.9 (0.14)	18 (0.14)	53.1 (0.10)	-14.1 (0.84)	51.9 (0.11)
12q	52.5 (0.16)	4.9 (0.29)	57.6 (0.03)	-12.4 (0.92)	52.2 (0.07)

Note: RMSE-statistic for main aggregates from ABM simulations in comparison to a VAR(1) for the forecast period from 2005:Q2-2019:Q4 for the euro area.

Hommes, C. H. & Poledna (2023)

Out-of-sample forecast performance of sectoral gross value added (GVA) for Austria

	A	B, C, D and E	F	G, H and I	J	K	L	M and N	O, P and Q	R and S
VAR(1)	*RMSE-statistic for different forecast horizons*									
1q	5.25	1.2	1.49	0.8	1.66	3.29	0.41	1.17	0.46	0.62
2q	7.32	1.71	1.93	1.15	2.01	3.63	0.6	1.57	0.61	0.83
4q	9.9	2.24	3.35	1.83	2.96	5.03	0.9	2.28	0.88	1.19
8q	10.76	2.83	5.99	2.96	2.75	4.58	1.22	3.75	1.46	1.86
12q	13.67	3.31	8.06	3.79	3.63	4.45	1.72	5.04	1.94	2.63
ABM	*Percentage improvements (+) or losses (-) relative to VAR(1) model*									
1q	0.5 (0.95)	-2.3 (0.82)	23.9 (0.04**)	-6.8 (0.40)	4.9 (0.47)	14.8 (0.04**)	-39.1 (0.01***)	-15.7 (0.24)	-1.3 (0.87)	12.3 (0.32)
2q	2.6 (0.36)	7.3 (0.18)	8.8 (0.04**)	-7.4 (0.61)	2.5 (0.82)	0.6 (0.90)	-90.2 (0.00***)	-14.1 (0.33)	-15.1 (0.34)	10.4 (0.52)
4q	8.4 (0.08*)	5.8 (0.17)	8.5 (0.01***)	-3.6 (0.88)	-2.8 (0.74)	1.8 (0.45)	-150.8 (0.00***)	-24.3 (0.36)	-34.3 (0.36)	14.5 (0.47)
8q	8.1 (0.44)	7.6 (0.16)	7.8 (0.00***)	15.6 (0.66)	-48.2 (0.01***)	5.8 (0.35)	-250 (0.00***)	-24.2 (0.51)	-54.4 (0.41)	28.7 (0.35)
12q	9.1 (0.39)	6.8 (0.21)	10.2 (0.09*)	38.4 (0.56)	-64.6 (0.00***)	5.4 (0.62)	-271 (0.00***)	-31.3 (0.51)	-74.1 (0.43)	27.5 (0.46)

Table: RMSE-statistic for sectoral gross value added (GVA) from ABM simulations in comparison to a VAR(1) models. GVA is shown for the sectors Agriculture, 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).

Poledna, S., Miess, M. G., Hommes, C., & Rabitsch, K. (2023)

Conditional forecast performance in comparison to DSGE

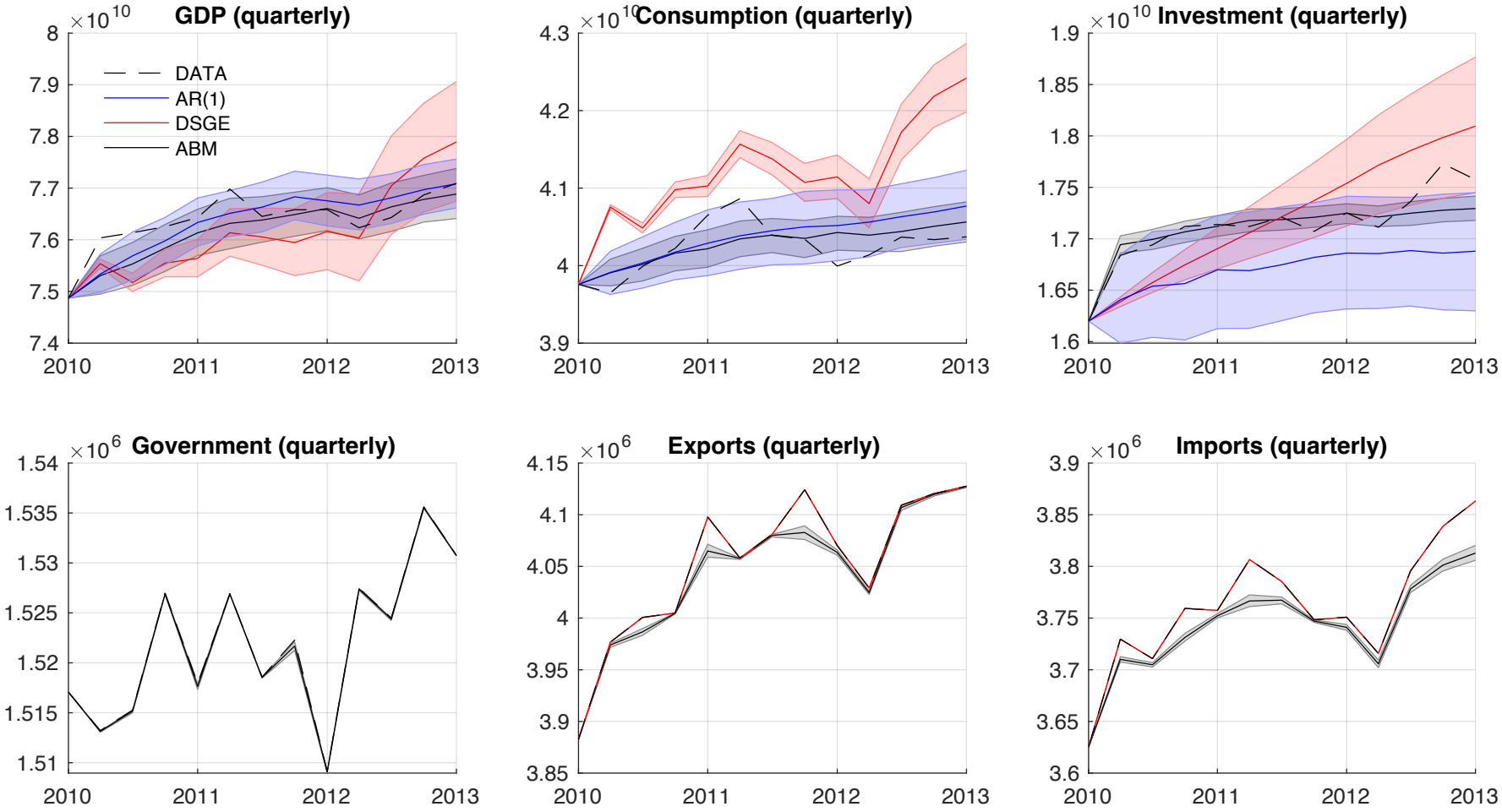
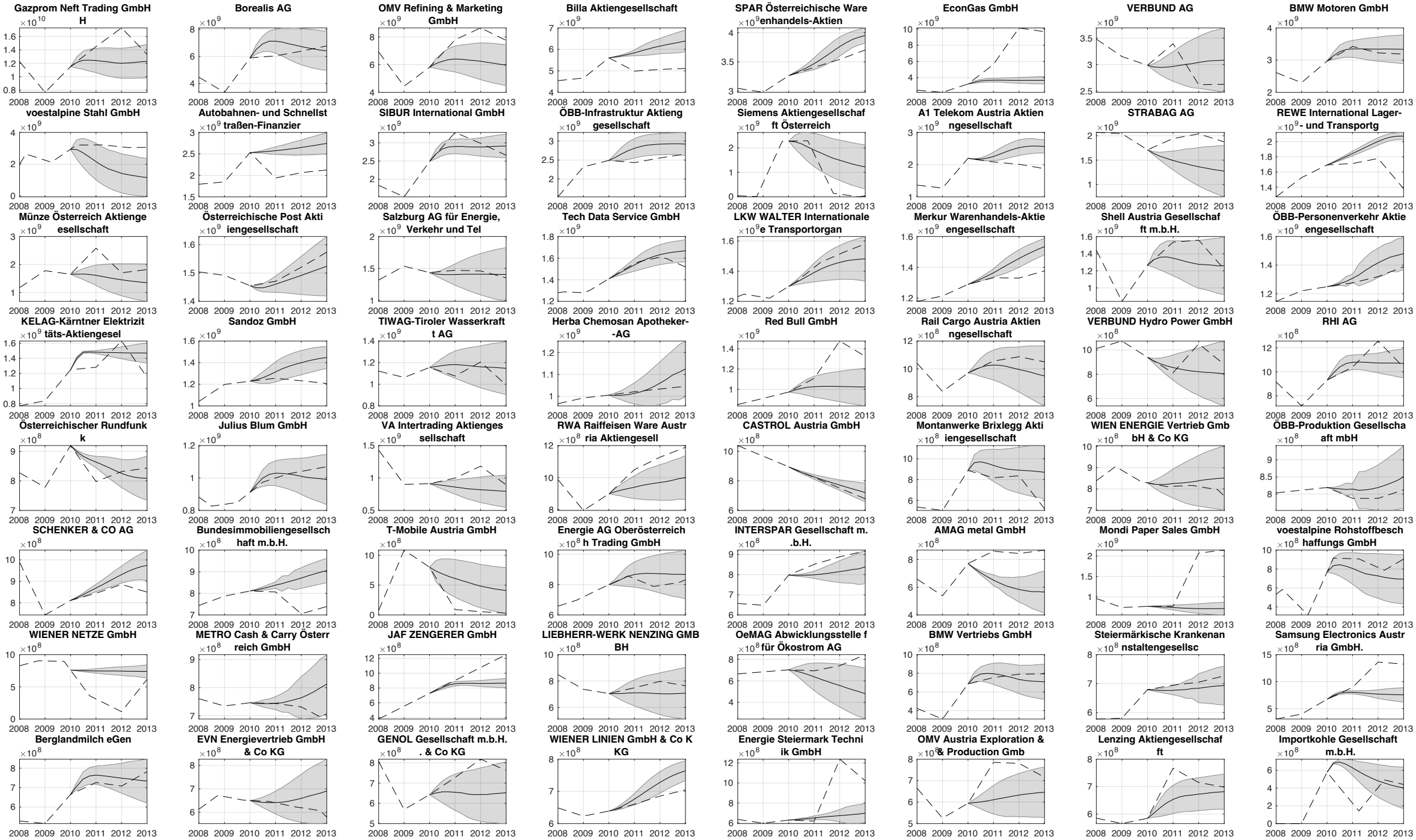


Figure: Comparison of ABM conditional forecasts (black), ARX(1) (blue), DSGE conditional forecasts (red), and observed Eurostat data for Austria (dashed line) for a forecast horizon of 12 quarters.

Earnings forecasts for Austrian firms

Based on the SABINA database from Bureau van Dijk

- Company financials, in a detailed format, with up to 10 years of history for 175.000 companies in Austria
- Directors, shareholders and subsidiaries
- Activity codes and trade descriptions
- Stock data for listed companies
- Detailed corporate structures and the corporate family Business and company-related news
- M&A deals and rumors


Gazprom Neft Trading GmbH
Borealis AG
OMV Refining & Marketing GmbH
Billa Aktiengesellschaft
SPAR Österreichische Warenhandels-Aktien
EconGas GmbH
VERBUND AG
BMW Motoren GmbH
voestalpine Stahl GmbH
Autobahnen- und Schnellstraßen-Finanzier
SIBUR International GmbH
ÖBB-Infrastruktur Aktiengesellschaft
Siemens Aktiengesellschaft Österreich
A1 Telekom Austria Aktiengesellschaft
STRABAG AG
REWE International Lager- und Transportg
Münze Österreich Aktiengesellschaft
Österreichische Post Aktiengesellschaft
Salzburg AG für Energie, Verkehr und Tel
Tech Data Service GmbH
LKW WALTER Internationale Transportorgane
Merkur Warenhandels-Aktiengesellschaft
Shell Austria Gesellschaft m.b.H.
ÖBB-Personenverkehr Aktiengesellschaft
KELAG-Kärntner Elektrizitäts-Aktiengesel
Sandoz GmbH
TIWAG-Tiroler Wasserkraft AG
Herba Chemosan Apotheker-AG
Red Bull GmbH
Rail Cargo Austria Aktiengesellschaft
VERBUND Hydro Power GmbH
RHI AG
Österreichischer Rundfunk
Julius Blum GmbH
VA Intertrading Aktiengesellschaft
RWA Raiffeisen Ware Austria Aktiengesell
CASTROL Austria GmbH
Montanwerke Brixlegg Aktiengesellschaft
WIEN ENERGIE Vertrieb GmbH & Co KG
ÖBB-Produktion Gesellschaft mbH
SCHENKER & CO AG
Bundesimmobiliengesellschaft m.b.H.
T-Mobile Austria GmbH
Energie AG Oberösterreich Trading GmbH
INTERSPAR Gesellschaft m.b.H.
AMAG metal GmbH
Mondi Paper Sales GmbH
voestalpine Rohstoffbeschaffungs GmbH
WIENER NETZE GmbH
METRO Cash & Carry Österreich GmbH
JAF ZENGERER GmbH
LIEBHERR-WERK NENZING GMBH
OeMAG Abwicklungsstelle für Ökostrom AG
BMW Vertriebs GmbH
Steiermärkische Krankenanstaltengesellsc
Samsung Electronics Austria GmbH.
Berglandmilch eGen
EVN Energievertrieb GmbH & Co KG
GENOL Gesellschaft m.b.H. & Co KG
WIENER LINIEN GmbH & Co KG
Energie Steiermark Technik GmbH
OMV Austria Exploration & Production Gmb
Lenzing Aktiengesellschaft
Importkohle Gesellschaft m.b.H.

Earnings forecasts to GDP

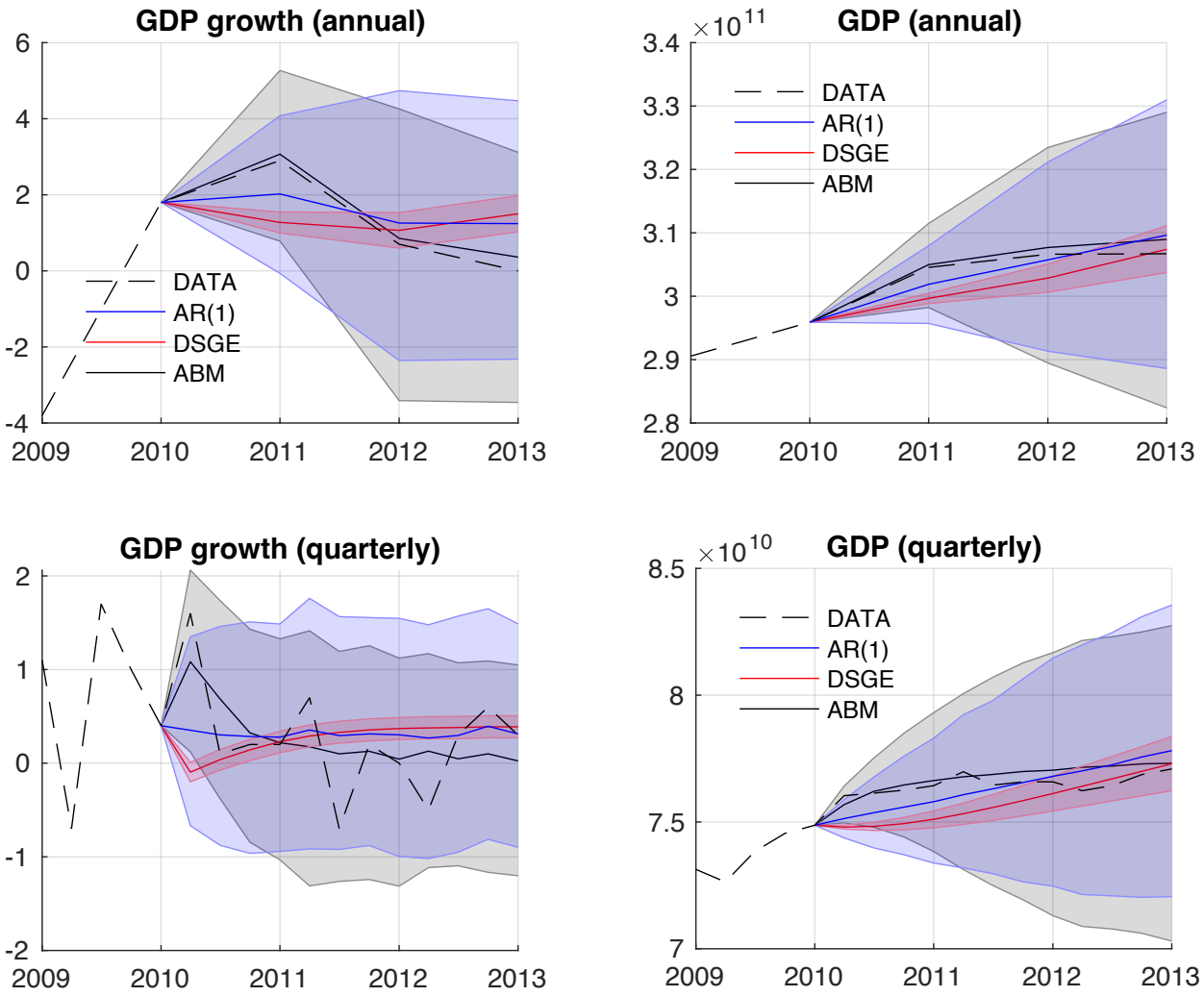


Figure: Comparison of ABM simulations with firm-level data (black), AR(1) (blue), DSGE (red), and observed Eurostat data for Austria (dashed line) for a forecast horizon of 12 quarters.

WIFO

ÖSTERREICHISCHES INSTITUT FÜR WIRTSCHAFTSFORSCHUNG

Sebastian Poledna

sebastian.poledna@wifo.ac.at

(+43 676) 31 95 744

https://www.wifo.ac.at/en/person/sebastian-poledna/