Economic forecasting with an agent-based model

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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
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 not 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.
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 \textbf{methodological framework} (Macroeconomics from the bottom-up).
- [Assenza et al., 2015]: \textbf{Starting point} for this model (macroeconomic ABM with capital and credit).

\(^1\)\url{http://www.crisis-economics.eu}, grant agreement no. 288501.
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

Government
- loans
- taxes
- consumption

Financial institutions
- deposits
- taxes
- dividends
- wages / dividends

Households
- consumption
- deposits

Firms
- imports
- exports
- dividends
- wages / dividends

Government
- loans
- taxes

Financial institutions
- loans
- deposits
- taxes

Households
- consumption
- deposits

Firms
- imports
- exports

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

- Output (P.1)\(^2\) → 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
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:

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

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:

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

\[ \pi^e(t) = \alpha^{\pi} \pi(t - 1) + \beta^{\pi} \epsilon^{\pi}(t - 1) + \epsilon^{\pi}(t) \] \(3\)
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 $Q_i^s(t)$:

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

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

$$P_i(t) = \frac{\text{Unit labour costs}}{\alpha_i(t)} + \frac{1}{\beta_i} \sum_g a_{sg} \bar{P}_g (t-1)(1 + \pi^e(t))$$

$$+ \frac{\delta_i}{\kappa_i} \bar{P}_{CF} (t-1)(1 + \pi^e(t)) + \tau_i^\gamma P_i(t-1)(1 + \pi^e(t))$$

$$+ \frac{\tau_i^K}{\kappa_i \omega} \bar{P}_{CF} (t-1)(1 + \pi^e(t)) + \bar{\pi}_i P_i(t-1)(1 + \pi^e(t))$$

$$+ \text{Unit material costs}$$

$$+ \text{Unit capital costs}$$

$$+ \text{Unit net taxes/subsidies products}$$

$$+ \text{Unit net taxes/subsidies production}$$

$$+ \text{Target unit operating surplus}$$

(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. \( \alpha_i, \beta_i \) and \( \kappa_i \): productivity coefficients, \( a_{sg} \) technologically determined input coefficients:

\[
Y_i(t) = \min \left( Q_i^s(t), \frac{\beta_i}{a_{s1}} M_{i1}(t - 1), \frac{\beta_i}{a_{s2}} M_{i2}(t - 1), \ldots, \frac{\beta_i}{a_{sg}} M_{ig}(t - 1), \alpha_i(t) N_i(t), \kappa_i K_i(t - 1) \right). \tag{6}
\]

Investment: according to depreciation \( \delta_i \), productivity of capital \( \kappa_i \), and desired scale of activity \( Q_i^s(t) \),

\[
I_{id}^i(t) = \delta_i Q_i^s(t) = \delta_i Q_i^e(t) = \delta_i Q_i^d(t - 1)[1 + \gamma^e(t)]. \tag{7}
\]
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:

\[ C^d_h(t) = \frac{\psi Y^e_h(t)}{1 + \tau \text{VAT}} , \]  

(8)

and on investment:

\[ I^d_h(t) = \frac{\psi^H Y^e_h(t)}{1 + \tau \text{CF}} , \]  

(9)

where \( \psi \) is the marginal propensity to consume and \( \psi^H \) the marginal propensity to invest out of expected income.

Savings is the difference between current disposable income \( Y^d_h \) and actual consumption expenditure \( C_h \), used to accumulate financial wealth

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

(10)
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)
General Government: Revenues

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

\[
\begin{align*}
\text{Social security contributions} & \quad (\tau^{SIF} + \tau^{SIW}) \bar{P}^{HH}(t) \sum_{h \in H^E(t)} w_h(t) + \\
\text{Net taxes/subsidies on products} & \quad \sum_{s,i \in I_s} \tau^Y_i P_i(t) Y_i(t) \\
\text{Labour income taxes} & \quad + \tau^{INC} (1 - \tau^{SIW}) \bar{P}^{HH}(t) \sum_{h \in H^E(t)} w_h(t) + \\
\text{Value added taxes} & \quad \tau^{VAT} \sum_{h} C_h(t) \\
\text{Capital income taxes} & \quad + \tau^{INC} (1 - \tau^{FIRM}) \theta^{DIV} \left( \sum_{i} \max(0, \Pi_i(t)) + \max(0, \Pi_k(t)) \right) \\
\text{Corporate income taxes} & \quad + \tau^{FIRM} \left( \sum_{i} \max(0, \Pi_i(t)) + \max(0, \Pi_k(t)) \right) + \\
\text{Taxes on capital formation} & \quad \tau^{CF} \sum_{h} l_h(t) \\
\text{Net taxes/subsidies on production} & \quad + \bar{P}^{CF}(t) \sum_{i} \tau^K_i K_i(t) + \\
\text{Export taxes} & \quad \tau^{EXPORT} \sum_{l} C_l(t). 
\end{align*}
\]
General Government: deficit & debt

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

\[
\Pi^G(t) = Y^G(t) - \sum_j C_j(t) - r^G L^G(t) - \sum_{h \in H^{inact}} \bar{P}^{HH}(t) sb^{inact} + \sum_{h \in H^U(t)} \bar{P}^{HH}(t) w_h(t) + \sum_{h} \bar{P}^{HH}(t) sb^{other}.
\]

(12)

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

\[
L^G(t) = L^G(t-1) + \Pi^G(t).
\]

(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.
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

<table>
<thead>
<tr>
<th></th>
<th>GVA</th>
<th>GVA deflator</th>
<th>Household consumption</th>
<th>Investment</th>
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<tbody>
<tr>
<td><strong>ABM</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1q</td>
<td>0.42</td>
<td>0.28</td>
<td>0.88</td>
<td>3.75</td>
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<tr>
<td>2q</td>
<td>0.49</td>
<td>0.46</td>
<td>1.12</td>
<td>3.56</td>
</tr>
<tr>
<td>4q</td>
<td>0.54</td>
<td>0.85</td>
<td>1.68</td>
<td>4.18</td>
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<td>8q</td>
<td>0.71</td>
<td>1.71</td>
<td>2.01</td>
<td>3.60</td>
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<td>12q</td>
<td>0.58</td>
<td>2.44</td>
<td>2.24</td>
<td>4.16</td>
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<td><strong>ARMAX(1,1)</strong></td>
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<td></td>
</tr>
<tr>
<td>1q</td>
<td>100.14</td>
<td>98.99</td>
<td>81.09</td>
<td>88.01</td>
</tr>
<tr>
<td>2q</td>
<td>156.82</td>
<td>118.69</td>
<td>97.10</td>
<td>102.21</td>
</tr>
<tr>
<td>4q</td>
<td>246.93</td>
<td>120.76</td>
<td>135.41</td>
<td>137.84</td>
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<tr>
<td>8q</td>
<td>328.38</td>
<td>97.57</td>
<td>183.76</td>
<td>224.35</td>
</tr>
<tr>
<td>12q</td>
<td>300.61</td>
<td>139.97</td>
<td>145.81</td>
<td>227.19</td>
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<tr>
<td><strong>VARX(1)</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>1q</td>
<td>101.59</td>
<td>98.58</td>
<td>106.27</td>
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<td>2q</td>
<td>158.17</td>
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<tr>
<td>12q</td>
<td>755.43</td>
<td>160.81</td>
<td>295.11</td>
<td>198.91</td>
</tr>
</tbody>
</table>

**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.
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

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


