Structured Macroeconomics: a self-deploying modeling and simulation approach

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Abstract

This article presents an agent-based macroeconomics modeling framework that can read a Social Accounting Matrix (SAM) and build an economic system (active population, activity sectors acting as firms, a central bank, government, external sectors...) whose structure and activity replicate the economy at the time of the SAM snapshot. The main feature of the approach is the ability of the emergent macroeconomic system to adapt itself to subsequent changes, including the sustained dynamic evolution from initial models with simple behavioral rules towards models with increasingly complex behavior.

Introduction

A recurring complaint from economics policymakers is the lack of helpful macroeconomic models and tools: “When the crisis came, the serious limitations of existing economic and financial models immediately became apparent. Arbitrage broke down in many market segments, as markets froze and market participants were gripped by panic. Macro models failed to predict the crisis and seemed incapable of explaining what was happening to the economy in a convincing manner. As a policymaker during the crisis, I found the available models of limited help. In fact, I would go further: in the face of the crisis, we felt abandoned by conventional tools.” [Trichet2010]

At the time that John M. Keynes delineated his framework for a systematic modeling of macroeconomics [Keynes1936], models were analytical due to their simplicity, that only described the main guidelines of the economy. An economic system can be modelled as a dynamic structure (“hardware”: households, firms, Banks, Government...) driven by behavioral rules (“software”: demand-supply, price setting, fiscal and monetary policies, trusts...) [Jaraiz2020]. With the advent of computers, the quest for more detailed and accurate models led to a sustained effort to improve mainly the behavioral rules, disregarding the key role of a more detailed representation of the structure of the economic system. This bias to focus on the rules can have been fostered by the fact that in the analytical modeling approach, increasing the disaggregation soon leads to prohibitive computational burden.

The tenet of the present paper is twofold: (I) the level of detail (disaggregation) of the structure plays a crucial role in macroeconomics modeling and simulation, and (II) agent-based modeling can efficiently handle highly disaggregated structures driven by complex behavioral rules.

Just as the mechanical engineering field once made the transition from the steam engine to the combustion engine to the electric motor, it may be time for economics to be boosted by alternative modeling techniques. As already pointed out [Dawid2019], agent-based modeling can easily and efficiently handle highly disaggregated structures. It has been proposed as a tool to be explored by, for example, [Trichet2010]: “The atomistic, optimising agents underlying existing models do not capture behaviour during a crisis period. We need to deal better with heterogeneity across agents and the interaction among those heterogeneous agents. We need to entertain alternative motivations for economic choices. Behavioural economics draws on psychology to explain decisions made in crisis circumstances. Agent-
based modeling dispenses with the optimisation assumption and allows for more complex interactions between agents. Such approaches are worthy of our attention.”

In fact, several agent-based macroeconomics modeling environments have already been developed, see [Dawid2018] for a review. However, most of them have been used to conduct research in different specific domains of economic policy rather than as a general purpose, comprehensive simulator of the actual economy of a region or set of regions like, for example, the European Union. Strikingly, none of the four main models valid for the euro area listed recently by [Blanchard2021] are agent-based.

Using an analogy with road traffic, the drivers’ behavior can be similar in, for example, Madrid or Paris. However, to assess or design routes to alleviate traffic congestion in those cities, it is essential to have a sufficiently disaggregated roadmap, with not only the contour of the major industrial, commercial, and residential areas but also their internal main roads, squares, and roundabouts. In order to implement a realistic traffic simulator, knowledge of this more detailed structure, supplemented with a small set of simple behavioral rules, can be more helpful than a simplistic structure of black boxes with complex behavioral rules.

Similarly, considered as macroeconomic systems, the main difference between Madrid and Paris, or between Spain and France, can be expected to arise from the differences in their economic structures, rather than from their agent’s behaviors. Most developed countries already have access to a large amount of data about their own economic structure and can easily collect any other data if needed. The stumbling block, however, is the lack of an appropriate software that could take this enormous amount of data and simulate the flow of wealth as, for example, some mapping applications do with global road traffic on the Internet, not to the minute as in traffic, but on a month or quarter time step scale. The aim of the present work is to explore whether this is possible with an agent-based self-deploying simulation approach [Jaraiz2020], adapted to replicate the economy of a region, or set of regions, using SAM data for calibration.

Specifically, the approach presented here is an attempt to develop an agent-based framework that can read a Social Accounting Matrix and build an economic system (active population, activity sectors as firms, a central bank, government, external sectors...) whose structure and activity replicate the SAM economy at the time of the snapshot. The subsequent evolution depends on the behavioral rules defined by the modeler. As a framework, it only provides basic initial agent models, but it allows the modeler to incorporate models of increasing complexity. This is possible thanks to the plasticity of the economic system itself, which modifies its structure through the demand-supply mechanism to respond to endogenous or exogenous stimuli. The aim of this modeling approach is to develop a tool that, eventually, could tackle the task of simulating global macroeconomics with highly disaggregated heterogeneous agents. For the simple rules included in the example, one thousand (active) individuals is enough to get statistically acceptable results and takes about five minutes on a 4 GHz CPU. Since individuals can have a limited number of interactions per month, CPU time increases linearly with the number of individuals simulated. Regarding memory requirements, 200,000 individuals take about 2 GB, and the simulator can still be optimized for speed and memory.

**Modeling approach**

The framework is a follow-up of the one described in [Jaraiz2020]. As simple example, we have chosen a SAM of Spain [MCAESP08], Fig.SAM, with only five producing sectors and an initial model with basic behavioral rules for the agents. In the model, individuals can work as employees, apply for loans in a Bank or try to start new firms, of types chosen from the production sectors listed in the SAM and most demanded in the neighborhood. When a non-profitable firm is closed the owner searches for a job as
employee and can later try to start another firm. Prices evolve in response to simple demand-supply rules from interaction with neighbors.

During an initial stabilization stage, individuals deploy a variable number of firms of the SAM’s activity sectors until the activity level closely reproduces the experimental values (output, unemployment, final and intermediate consumptions,..., Fig.MCAESP08). To find this production structure and activity level, the final consumer agents (households, government, external sectors) are initially set to buy repeatedly their SAM values every month (Fig.HomeGoods). Throughout this initial stage (e.g., 60 months), producers try to buy their intermediate consumption (IC) goods from their neighbors, but they are allowed to produce the desired output even if they failed to gather some of the necessary IC goods (missing IC goods). The stabilization stage ends once the economic system is self-sustained, that is, when the missing IC goods become negligible. From there on, gathering of the necessary IC goods is strictly enforced.

After the stabilization stage the economy is in equilibrium and the final consumption is correct but, for example, the level of unemployment is not. At this new stage (initial calibration), the simulator adjusts “effective” values of some parameters (such as the initial average salary, stock level of firms and others) of the basic demand-supply model. As an example of parameter calibration, the initial average salary can be first estimated from the SAM’s active population, level of unemployment and compensation of employees. However, to get the correct SAM level of unemployment in the simulation it is necessary to use an effective initial average salary through a correction factor that is adjusted from step 60 and settles at a value around 1.24 before step 240 (Fig.Unemployment).

Once the economy of the initial model is in equilibrium at the correct SAM levels, it is ready to respond as a ‘live’ system to exogenous shocks or even to a smooth evolution towards different, increasingly complex models. To do this, the basic behavior of agents is gradually replaced by more complex rules defined by the modeler. The system is self-adapting and follows the changing demand through changes in its structure (number and size of producing firms, households’ wealth distribution...). In this example, after the initial calibration stage, each household consumption budget \( C_h \) is switched from the fixed SAM value (\( C_{SAM,t} \) same for all households) to an income and wealth-dependent value given by following “buffer stock” rule [Dawid2019]:

\[
C_{h,t}^* = \tilde{t}_{h,t}^{\text{Mean}} + \kappa \cdot \left( W_{h,t} - \Phi \cdot \tilde{t}_{h,t}^{\text{Mean}} \right)
\]

The input file table for the [MCAESP08] SAM is listed in the Supporting Information. Other SAMs like SAMERS08 [MCAESP08], [SAMEXT90] and [SAMEXT90disag] can be readily simulated preparing similar input files. To make the correct assignments there are some naming conventions for the accounts’ names. For example, taxes begin with \( T \) followed by the account ordinal and one of a small set of tax labels (SSocEmployer, IRPF...) that have been implemented (assignments), like T11_SSocEmployer and T14_IRPF. This methodology can also be applied to Supply-Use Tables (SUT) instead of SAM or Input-Output Tables (IOT).

**Conclusion**

The simulation approach presented proposes a framework to implement arbitrarily complex economic structures and behavioral rules chosen by the modeler. It has been developed in the hope that it will make it possible to disaggregate the system’s economic structure to a level of detail beyond the currently attained. This higher degree of correspondence between the real and the simulated system architecture adds constraints that favor the correspondence between the real and simulated behavior. Besides, increasing the real and simulated system similarity in its structure is much easier than in its behavioral rules, because the first can be objectively known in detail while the rules must be guessed and depend on
the modeler. Therefore, it may be worth exploring this expected improved simulation accuracy arising from a much more detailed structure.

References

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| SPAIN          | Year: 2008 | Population: 40000000 | Active: 20000000 | P01_AgroPesc | P02_EnerPetro | P03_Indust | P04_Constru | P05_ServVenTa | P06_ServVenTa | P07_GFCF | X08_SectExt |
|---------------|-----------|-----------------------|------------------|--------------|--------------|------------|--------------|--------------|--------------|-----------|-------------|
| P01_AgroPesc  | 1701      | 1                     | 24972            | 24           | 2877         | 302        | 811          | 7834         |             |           |             |
| P02_EnerPetro | 1119      | 41384                 | 19205            | 2678         | 21061        | 6438       | 292          | 6740         |             |           |             |
| P03_Indust    | 8616      | 5037                  | 209653           | 64805        | 76816        | 21507      | 65355        | 144645       |             |           |             |
| P04_Constru   | 290       | 793                   | 1909             | 108372       | 25997        | 3664       | 176139       | 144          |             |           |             |
| P05_ServVenTa | 3682      | 10762                 | 94885            | 31726        | 244738       | 49376      | 54460        | 70689        |             |           |             |
| P06_ServVenTa | 0         | 0                     | 0                | 0            | 0            | 0          | 0            | 0            |             |           |             |
| P07_GFCF      | 0         | 0                     | 0                | 0            | 0            | 0          | 0            | 0            |             |           |             |
| X08_SectExt   | 8742      | 35259                 | 238669           | 804          | 60405        | 1085       | 0            | 103916       |             |           |             |
| L06_CompEmplo | 4259      | 4220                  | 62958            | 50681        | 200109       | 83364      | 0            | 0            |             |           |             |
| K10_GrossOpSurplus | 19003 | 17790                 | 48917            | 46113        | 321369       | 14019      | 0            | 0            |             |           |             |
| T11_SocEmplo  | 624       | 1543                  | 19007            | 15518        | 53763        | 26223      | 0            | 0            |             |           |             |
| T12_TaxProduc | .244      | .120                  | -.137            | .204         | 1118         | .53        | 0            | 0            |             |           |             |
| T13_TaxProduc | -.473     | .307                  | -.1082           | .1555        | 12274        | 4100       | 21578        | .92          |             |           |             |
| T14_Households| 0         | 0                     | 0                | 0            | 0            | 0          | 0            | 0            |             |           |             |
| H15_Government| 0         | 0                     | 0                | 0            | 0            | 0          | 0            | 0            |             |           |             |
| H16_Households| 0         | 0                     | 0                | 0            | 0            | 0          | 0            | 0            |             |           |             |
| colSUM        | 48021     | 117166                | 718896           | 322480       | 1020327      | 215131     | 318632       | 344964       |             |           |             |

| Nproducers: 8 | Naccounts: 16 | Units: 1000000 | euros |
|---------------|---------------|---------------|-------|
| L09_CompEmplo | K10_GrossOpSurplus | T11_SocEmplo | T12_TaxProduc | T13_TaxProduc | T14_Households | H15_Government | H16_Households | colSUM |
| 0             | 0             | 0             | 0             | 0             | 0             | 0             | 0             | 0          |
| 0             | 0             | 0             | 0             | 0             | 0             | 0             | 0             | 0          |
| 0             | 0             | 0             | 0             | 0             | 0             | 0             | 0             | 0          |
| 0             | 0             | 0             | 0             | 0             | 0             | 0             | 0             | 0          |
| 0             | 0             | 0             | 0             | 0             | 0             | 0             | 0             | 0          |
| 0             | 0             | 0             | 0             | 0             | 0             | 0             | 0             | 0          |
| 0             | 0             | 0             | 0             | 0             | 0             | 0             | 0             | 0          |
| 0             | 0             | 0             | 0             | 0             | 0             | 0             | 0             | 0          |

| 410591 | 467771 | 136752 | 1114 | 92348 | 117483 | 347697 | 983902 |

| 410591 | 467771 | 136752 | 1114 | 92348 | 117483 | 347697 | 983902 |
| A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| A1 | B1 | C1 | D1 | E1 | F1 | G1 | H1 | I1 | J1 | K1 | L1 | M1 | N1 | O1 | P1 | Q1 | R1 | S1 | T1 | U1 | V1 | W1 | X1 | Y1 | Z1 |
| A2 | B2 | C2 | D2 | E2 | F2 | G2 | H2 | I2 | J2 | K2 | L2 | M2 | N2 | O2 | P2 | Q2 | R2 | S2 | T2 | U2 | V2 | W2 | X2 | Y2 | Z2 |
| A3 | B3 | C3 | D3 | E3 | F3 | G3 | H3 | I3 | J3 | K3 | L3 | M3 | N3 | O3 | P3 | Q3 | R3 | S3 | T3 | U3 | V3 | W3 | X3 | Y3 | Z3 |
| A4 | B4 | C4 | D4 | E4 | F4 | G4 | H4 | I4 | J4 | K4 | L4 | M4 | N4 | O4 | P4 | Q4 | R4 | S4 | T4 | U4 | V4 | W4 | X4 | Y4 | Z4 |
| A5 | B5 | C5 | D5 | E5 | F5 | G5 | H5 | I5 | J5 | K5 | L5 | M5 | N5 | O5 | P5 | Q5 | R5 | S5 | T5 | U5 | V5 | W5 | X5 | Y5 | Z5 |
| A6 | B6 | C6 | D6 | E6 | F6 | G6 | H6 | I6 | J6 | K6 | L6 | M6 | N6 | O6 | P6 | Q6 | R6 | S6 | T6 | U6 | V6 | W6 | X6 | Y6 | Z6 |
| A7 | B7 | C7 | D7 | E7 | F7 | G7 | H7 | I7 | J7 | K7 | L7 | M7 | N7 | O7 | P7 | Q7 | R7 | S7 | T7 | U7 | V7 | W7 | X7 | Y7 | Z7 |
| A8 | B8 | C8 | D8 | E8 | F8 | G8 | H8 | I8 | J8 | K8 | L8 | M8 | N8 | O8 | P8 | Q8 | R8 | S8 | T8 | U8 | V8 | W8 | X8 | Y8 | Z8 |
| A9 | B9 | C9 | D9 | E9 | F9 | G9 | H9 | I9 | J9 | K9 | L9 | M9 | N9 | O9 | P9 | Q9 | R9 | S9 | T9 | U9 | V9 | W9 | X9 | Y9 | Z9 |

**Notes:**
- This table contains data from a spreadsheet.
- Each column represents a different category of data.
- The rows are labeled with months (A1 to Z9).
- Specific values are listed in each cell, indicating measurements or calculations.
INPUT_FILE

INPUT_PARAMETERS
nIndividuals 1000
StepsBetweenUpdates 12
MaxYears 60

SaveSteps 59 110 470

ReleasePricesAt 48
AssistedProductionUpto 60
AdjustUnemploymentFrom 60
SetPricesToOneAt 120
PropToConsumeFrom 120
PropToConsume 0.6
AdjustUnemploymentUpto 480

SAM_table { MCAESP08
SPAIN; Year: ;2008; Population: ;40000000; Active: ;20000000; InitUnemp: ;12;Nproducers: ;8;Naccounts: ;16;Units: ;10000000;euros ;
P01_AgroPesc;1701;1;24972;24;2877;302;811;7834;0;0;0;0;0;9499;
P02_EnerPetro;1119;41384;19205;2678;21061;6438;292;6740;0;0;0;0;0;18249;
P03_Indust;8616;5037;209653;64805;76816;21507;65355;144645;0;0;0;0;0;7620;114842;
P04_Construc;190;793;108372;25997;3654;176136;144;0;0;0;0;0;5285;
P05_ServVenta;3682;10762;94805;31726;244738;49376;54460;70689;0;0;0;0;0;21238;438851;
N06_ServNoVenta;0;0;0;0;0;0;0;0;0;0;0;0;0;0;211972;3159;
F07_GFCF;0;0;0;0;0;103916;0;0;0;0;0;12014;202702;
X08_SectExt;8742;35259;238669;804;60405;1085;0;0;0;0;0;0;0;0;0;0;
L09_CompEmployees;4259;4220;62958;50681;200109;88364;0;0;0;0;0;0;0;0;0;0;
K10_GrossOpSurplus;19803;17740;48917;46113;321169;14029;0;0;0;0;0;0;0;0;0;0;
T11_SSocEmployer;624;1543;19007;15518;53763;1085;0;0;0;0;0;0;0;0;0;0;
T12_TaxProduction;244;120;137;204;1118;53;0;0;0;0;0;0;0;0;0;0;
T13_TaxProducts;471;307;1062;1555;12274;4100;21578;92;0;0;0;0;0;401;53758;
T14_IRPF;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;117483;
G15_Government;0;0;0;0;0;0;0;136752;1114;92348;117483;0;0;
H16_Households;0;0;0;0;0;0;0;11088;410591;467771;0;0;0;94452;0;
}