DEPLOYERS: An agent-based modeling tool for multi-country real-world data

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Abstract

We present recent progress in the design and development of DEPLOYERS, an agent-based macroeconomics modeling (ABM) framework, capable to deploy and simulate a full economic system (individual workers, goods and services firms, government, central and private banks, financial market, external sectors…) whose structure and activity analysis reproduce the desired calibration data, that can be, for example a Social Accounting Matrix (SAM) or a Supply-Use Table (SUT) or an Input-Output Table (IOT). Here we extend our previous work to a multi-country version and show an example using data from a 46-countries 64-sectors FIGARO Inter-Country IOT. The simulation of each country runs on a separate thread or CPU core to simulate the activity of one step (month, week, or day) and then interacts (updates imports, exports, transfers…) with that country's foreign partners, and proceeds to the next step. This interaction can be chosen to be aggregated (a single row and column IO account) or disaggregated (64 rows and columns) with each partner. A typical run simulates thousands of individuals and firms engaged in their monthly activity and then records the results, much like a survey of the country's economic system. This data can then be subjected to, for example, an Input-Output analysis to find out the sources of observed stylized effects as a function of time in the detailed and realistic modeling environment that can be easily implemented in an ABM framework.

Keywords Agent-based macroeconomics. Policy making. FIGARO tables. Agent-based modeling (ABM). Input-Output Models

JEL Classification C63 · E17

1. Introduction

Policy making usually refers to decisions made at top levels, such as a government or a central bank. But the increasing availability of appropriate data and tools (software) is leading private companies and institutions to also use them as a valuable source of advice to help them make their decisions. This, in turn, can lead to better dynamic self-adjustment of the economic system and thus reduce frictions and alleviate the task of governments and central banks in helping to keep the system running smoothly.

Ideally, in macroeconomics it would be better to operate at a more disaggregated level because, for example, some sectors may be more sensitive than others to a change in the interest rate or electricity tax. Again, from a modeling point of view, a macroeconomic system can be compared to a living being, i.e., a complex and constantly changing system composed of different interacting organs. Today, instrumentation plays a fundamental role in any hospital, although it would be useless without physicians. Similarly, it is desirable to improve the tools for macroeconomics to help economists understand why a complex system is malfunctioning, which sectors or subsectors are responsible and what can be done to bring it back on track without harming other sectors.

One reason for trying to introduce ABM into policy making is its potential to describe highly detailed economic structures and agent behaviors [1] and has been recommended as a tool worth to be explored [2]: "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. ... 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 macroeconomic modeling environments have already been developed (see [3] for a review). However, most of them have been used to conduct research in different specific areas of economic policy, and not as a general simulator of the real economy of a region or set of regions such as, for example, the European Union. Strikingly, none of the four main valid models for the euro area recently listed by [4] is agent-based. This work presents recent progress in the development of DEPLOYERS [5], an agent-based approach, following a Darwinian approach of survival of the fittest firms, which deploys and calibrates an economic system to reproduce, for example, a Social Accounting Matrix (SAM) or a Supply-Use Table (SUT) or an Input-Output Table (IOT) of a country, as we demonstrate using data from a FIGARO Inter-Country IOT of 46 countries with 64 sectors [6]. It should be noted that the ABM model used can, in principle, be arbitrary and that we have implemented a simple one only to test the calibration approach.

2. Description of the agent-based model used

As a basic example to describe the approach, we have chosen a SAM of Spain [7] with only six activity sectors and implemented a set of simple behavioral rules for the agents.

The implemented model (a modified version of the model described in [1]) simulates the activity of a population of households (active individuals) in a geographic region, initially without firms, with a government, a central bank (CB) and an external sector (rest of world, RoW). As the simulation progresses, some households will open firms of types (sectors) based on local demand, and some private banks. Also, a financial market will start as some firms reach a sufficiently large net worth. Unprofitable companies close and their owners look for work in their neighborhood. Prices evolve from interaction with neighbors following simple supply and demand rules.

Households initially have some monthly cash wages. They go out once every time step (month) on a random day to buy goods from the neighborhood, initially in the proportion given by the SAM (households consumption) but modulated with a logit probability as a function of prices. The consumption budget at step t, $C_{h,t}$, depends on the average income ($I_{h,t}$) and wealth ($W_{h,t}$) of each household, given by the following "buffer stock" rule:

$$C_{h,t} = I_{h,t} + \kappa \cdot (W_{h,t} - \phi \cdot I_{h,t}) \qquad (1)$$

where κ is a sensitivity parameter and ϕ a buffer size. Households divide their surplus into bank deposits and risky assets (equity shares of individual firms) in the stock market.

Initially there are no firms, but households without a firm have a certain probability of opening a new one of the most frequently demanded types in the neighborhood. Firms can borrow from banks and have a random but fixed day of the month for their productive activity. They can sell their stock on any day to households or to other firms for intermediate consumption (IC). Each firm attempts to produce enough to replenish a level of inventories that is estimated based on recent demand. If the firm has liquidity needs to finance production (IC and taxes according to its SAM column ratios, plus labor and capital according to a Cobb-Douglas or Leontief model) it can apply for a bank loan and the subsequent production volume is conditioned to the outcome of the application. In addition, if a company meets the requirements to enter the stock market, it can also issue new shares. After taxes are paid, a fraction of the profits is distributed as dividends to the owner or shareholders, and the remainder is deposited in the payment account.

To account for all the economic activities, capital goods are also produced like consumption goods, regardless of their use: a new door can be used as gross fix capital formation (GFCF) for a new building or as a consumption good to replace another door in an old building. We use the coefficients in the GFCF column of the SAM to distribute a GFCF value into its goods and services components.

A basic Stock market model takes place in a clearing house which collects at the end of the month all the sell and buy orders (sorted from high to low price) and allocates them starting with the high price orders. Prices are readjusted following the supply and demand rule mentioned above.

Banks can be founded by households that meet the criteria defined by the Central Bank, such as a minimum initial net worth and a maximum number of banks. We have implemented the model described in [1], in which the bank's ability to extend credit is constrained by a capital adequacy requirement (CAR) and a reserve requirement ratio (RRR), but with a simple first-come, first-served response to loan applicants. The interest rate offered to a firm is an increasing function of credit risk, based on the firm's probability of default on the loan, which is estimated from its debt-to-equity ratio.

The government, according to the data provided by the SAM, collects taxes and redistributes them in the form of subsidies (unemployment) to households and public spending. In our simple model, the government uses the Central Bank to deposit or withdraw its surplus or deficit, respectively.

The external sector, like the government, is implemented as a simple input-output or consumer (SAM column) - producer (SAM row of IC for firms) account.

3. The self-deployment approach

Here we provide a summary of [5]. The deployment of the economic system is based on a simple Darwinian survival of the fittest approach. Initially there are no firms, only the active population, the government, the CB, and the external sector. To build up the production structure (number, fixed capital size, number of employees, and activity level of firms), it is initially established that the final consuming agents (households, government, and external sectors) repeatedly try to buy from neighbors their SAM value every month. During an initial deployment stage, individuals open firms corresponding to activity sectors of the SAM, and close unprofitable ones, until the production levels match the experimental values (output, unemployment, final and intermediate consumption). Producers also try to buy from the firms in their neighborhood the IC goods they need. The deployment stage ends when the economic system reaches the desired level of activity. Then follows a calibration stage, at constant demand levels, until the system reaches a steady state (constant average stock levels, unemployment...).

This configuration snapshot (the deployed, self-sustaining economic system) can be saved as an initial state to run different what-if tests. From this initial state on, the system is allowed to freely evolve according to the demand, supply and behavioral rules established by the model, without imposing the SAM's consumption quantities. For example, each household consumption budget follows eq. (1). For a fuller explanation, see Ref. 5.

4. Calibration with the inter-country FIGARO tables

This self-deployment approach has proven to achieve convergence to a stable economic system using larger IO tables with more than 30 sectors (Ref. 5). The DEPLOYERS implementation ca now be calibrated with intercountry databases like the 46-countries, 64-sectors FIGARO Input-Output Tables.

The simulation of each country runs on a separate thread (or CPU core) to simulate the activity of one step (month, week, or day) and then interacts (updates imports, exports, transfers…) with that country's foreign partners and proceeds to the next step. This interaction can be chosen to be aggregated (a single row and column) or disaggregated (64 rows and columns) for each partner. A typical run simulates thousands of individuals and firms engaged in their monthly activity and then records the results, very much like a survey of the country's economic system. This data can then be subjected to, for example, an Input-Output analysis to find out the sources of observed stylized effects as a function of time in the detailed and realistic modeling environment that can be easily implemented in an ABM framework.

As an example, a typical personal computer with 4 cores can run the simulation of Spain with France as disaggregated, and with Germany, the US, and the Rest of World (RoW) each as aggregated external sectors. The three countries are each simulated at a core. The CPU time is approximately 2 to 4 times the simulation of only Spain and the RoW, because of the 64 external sectors rows and columns from France (disaggregated). Memory requirements are not a limiting factor. Thus, hardware with 46 cores can run a World simulation with the 46 countries (plus the RoW, different but constant for each country), each interacting in detail with a few of its most active partners.

Figure 1 shows an example of deployment (up to step 120), calibration (up to step 240), and simulation of Spain (in this simulation, the other 35 countries were assembled with the RoW into a single exogenous sector) using the FIGARO intercountry input-output, industry by industry, 2018 table (64 sectors, 46 countries).

The households increase their consumption due to their increasing wealth. The gross output plot rises with demand up to step 360 but afterwards the output gap (real production minus its potential level) becomes increasingly negative because there is almost full employment (not shown). The economic system has reached its potential GDP output [8] because, in the simple model implemented here, there is constant technology. The subsequent exponential decline to zero can be explained by a positive feedback: to purchase their intermediate consumption (IC) goods, firms must compete with households and, since the economy is at full production, some firms fail to buy enough IC to produce and must close, and this aggravates the situation. Normally, the government or other agents take measures in advance to prevent a free fall of the economic system. For example, in August 2020, hundreds of thousands of Californians briefly lost power in rolling blackouts amid a heat wave, marking the first time outages were ordered in the state due to insufficient energy supplies in nearly 20 years [9].

For an active population of 3680 workers per country this simulation takes 2 CPU hours.

5. Conclusion

The methodology presented allows the use of agent-based models for real-world economies and, in principle, can be used to calibrate any ABM model using readily available inter country databases like FIGARO Input-Output Tables. This self-deployment and calibration methodology, based on a Darwinian survival of the fittest approach, opens the way to the use of ABM as a tool for policy makers dealing with complex data from real macroeconomic systems. It also enables the expected high performance of ABM models to address the complexities of current global macroeconomics, such as ecology, epidemiology, or social networks, as well as other areas of interest.

References

[1] H. Dawid, P. Harting, S. van der Hoog, M. Neugart, Macroeconomics with heterogeneous agent models: fostering transparency, reproducibility and replication. *Journal of Evolutionary Economics* **29**, 467–538 (2019).

[2] J.-C. Trichet, President of the ECB, Opening address at the ECB Central Banking Conference, Frankfurt, 18 November 2010.

[3] H. Dawid, D. Gatti, Agent-Based Macroeconomics. *SSRN Electronic Journal*. 10.2139/ssrn.3112074 (2018).

[4] O. Blanchard, A. Amighini, F. Giavazzi (2021) *Macroeconomics: a European perspective*, 4th edition, New York, Pearson, 2021.

[5] M. Jaraiz, R. Pinacho, 29th International Input-Output Association Conference, June 2023, Alghero, Italy.

[6] FIGARO ICIO tables, https://ec.europa.eu/eurostat/web/esa-supply-use-input-tables/database#CSV%20matrix%20format%20(FIGARO%202023%20edition).

[7] A. Cámara, M. Flores, P. Fuentes, Una Matriz de Contabilidad Social de España para el análisis del sector de las energías renovables. *Estadística Española* **55**, 149-176 (2013).

[8] Scott A. Wolla, "Minding the Output Gap: What Is Potential GDP and Why Does It Matter?" *Page One Economics*, Federal Reserve Bank of St. Louis, research.stlouisfed.org, May 2021.

[9] Meredith Deliso, Why California has blackouts: A look at the power grid - ABC News, https://abcnews.go.com/US/california-blackouts-power-grid/story?id=89460998, accessed March 2024.

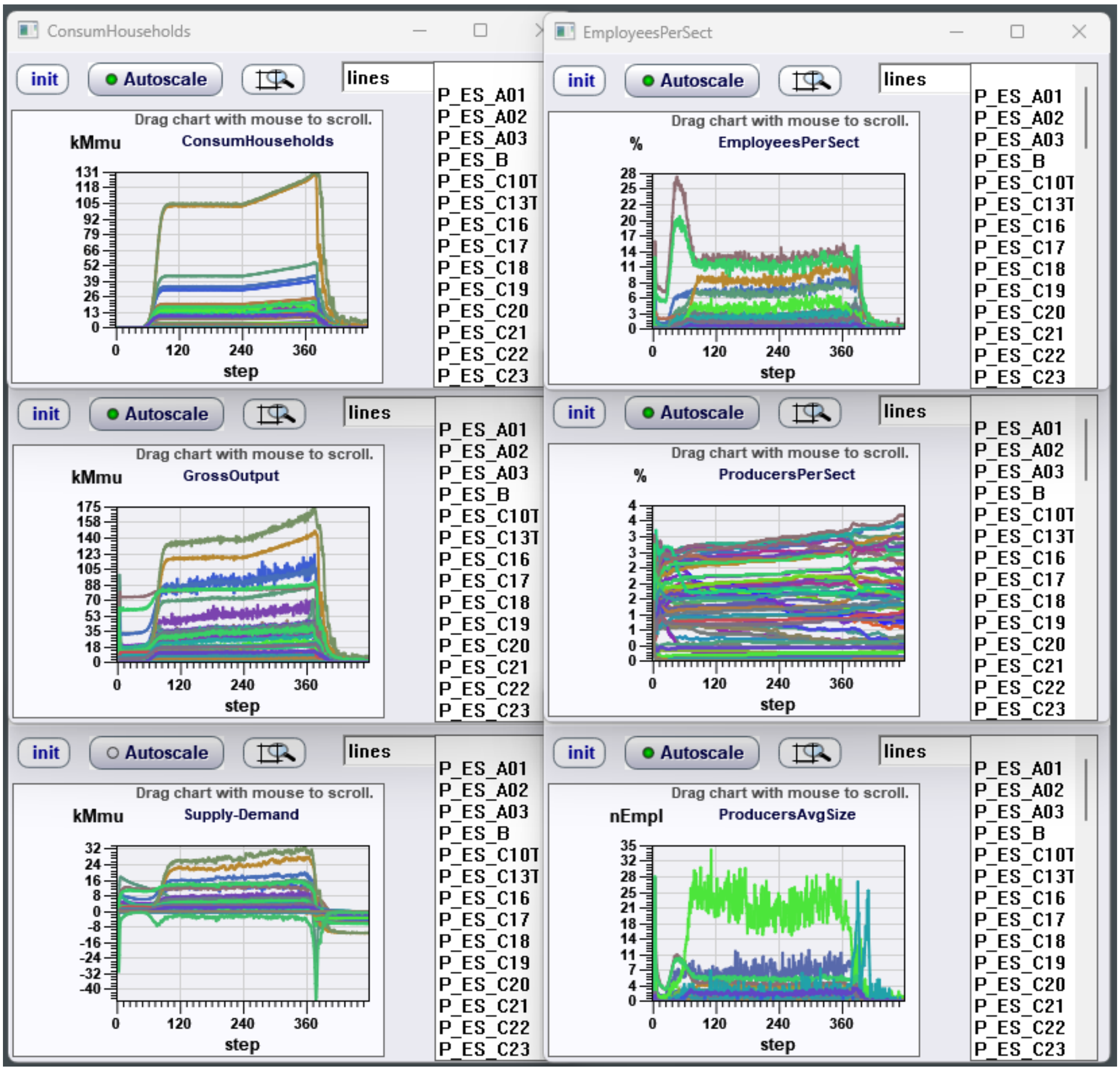

Figure 1. Example of deployment and calibration, up to month 240, of Spain (rest of World as a single external sector in this simulation) using the FIGARO intercountry input-output, industry by industry, 2018 table (64 sectors, 46 countries). The simulated active population is 3680, simulation time 2 CPU hours.