Macroeconomic Simulator with Multi-Layered Supplier–Customer Relationships

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Instead of setting an upstream and downstream structure of firms in the inter-firm networks, the model includes a mechanism that connects each firm through supplier–customer relationships and incorporates interactions between firms mutually buying and selling intermediate input materials. It is confirmed through the proposed model's simulation analysis that, although a firm's sales volume temporarily falls due to an economic shock of the type that causes a sharp decline in households' final demand, the increase in assets held by households as they refrain from spending rather expands their capacity for consumption.

agent-based model macroeconomic simulator supplier–customer network

1. Introduction

The real economy has been experiencing various economic shocks of varying magnitudes of impact, such as a sharp increase in the inflation rate in 2022 and an increase in policy interest rates in various countries. These economic shocks spread through various channels. Because economic shocks can potentially affect our real lives in various ways, it is important to develop an analytical framework capable of accurately capturing the propagation of a shock's effects. The agent-based model (ABM) is a modeling method that can represent the interactions of agents in minute detail Dawid and Gatti (2018) and has been used in a wide range of economic and social analyses Haldane and Turrell (2018).

Two approaches can be used to analyze economic shocks using ABM: the macroeconomic approach Dosi et al. (2022), van der Hoog and Dawid (2015), Delli Gatti and Reissl (2022), in which models are constructed in a way that encompasses representative entities in the economy, and in which models are constructed by narrowing the analysis target to a specific area such as, for example, the corporate sector Hillman et al. (2021), Inoue and Todo (2019). The latter approach, which narrows the analysis target to the corporate sector, has been widely used in studies of the supplier–customer network (SCN) among firms, particularly in the context of economic shock analysis. Each of these two approaches has benefits and drawbacks. The macroeconomic approach has the advantage of being able to analyze the various interactions among economic agents; however, it has the disadvantage of simplifying the attributes and behaviors of each agent when modeling. In particular, modeling that broadly categorizes firms into two types, namely, capital and consumer goods firms, and which is commonly used in macroeconomic approaches, may result in the fixation of upstream and downstream firms in the inter-firm network, thereby biasing the propagation of the impact of economic shocks. According to the world input–output table (WIOT) and other sources, the trading relationship between industries is bidirectional, and no single industry

is always on the upstream side of the inter-industry exchange. As specified by Reissl et al. (2022), who analyzed the effects of lockdown measures using an input–output table, inter-industry networks create complex interactions. Meanwhile, an approach that narrows the domain makes it easier to construct an elaborate model for the domain under analysis, but it cannot capture interactions outside the domain.

2. Macroeconomic Approach and Agent-Based Computational Economics

This section summarizes the previous studies that utilized a macroeconomic approach. The use of ABMs in macroeconomic analysis has expanded over the past two decades, and interest in ABMs has grown even more since the Great Recession Dilaver et al. (2018). The term agent-based computational economics (ACE) is commonly used to describe macroeconomic research that uses ABMs. According to Brancacciom et al. (2021) and Di Guilmi (2017), research utilizing ACE from the perspective of post-Keynesian economics has been conducted, particularly by combining the ABM with the stock-flow consistent (SFC) model Godley and Lavoie (2007). The SFC model comprehensively and completely integrates the real and financial aspects of the economy through the adoption of strict accounting rules based on the quadruple-entry principle developed by Copeland (1949). According to Ohno and Nishi (2011), the SFC model does not treat intersectoral economic transactions as a black box, but rather incorporates them into the analytical perspective, allowing for a more accurate understanding of accounting coherence. The SFC model is vigorously pursued in post-Keynesian economics. While the SFC model has many desirable features, Caiani et al. (2014) and Kinsella (2011) pointed out several shortcomings of the SFC model. The traditional SFC model divides the economy into major institutional sectors, such as firms, households, banks, central banks, and governments, and is highly aggregated. This perspective affects the tracking of intra-departmental flows and makes it difficult to analyze the causes and effects of agent heterogeneity that occur within a sector or across sectors. In this regard, agent-based models centered on the concept of the economy as a complex adaptive system are helpful for overcoming many of these limitations.

Various ACE models exist, but Dilaver et al. (2018) identified three as representative ACE models: (1) the Keynes meets Schumpeter model (K&S), (2) the complex adaptive trivial system (CATS) model, and (3) the EURACE model.[1]

The K&S model, proposed by Dosi et al. in Dosi et al. (2006), Dosi et al. (2008), and Dosi et al. (2010), combines the elements of Keynesian demand dynamism and Schumpeterian innovation. It is characterized by an endogenous mechanism of technological development. The authors of Dosi et al. (2022) constructed a model consisting of capital goods firms, consumer goods firms, households, banks, the government, and the central bank to analyze the impact of technological innovation on the working environment. The model analyzes the impact of technological innovation as it spreads through a process in which capital goods firms are the primary actors in technological innovation. The capital goods firms provide goods manufactured by capital goods firms to consumer goods firms. Delli Gatti and Gallegati developed the CATS model Delli Gatti et al. (2005, 2006), Dawid and Gatti (2018), and their collaborators Caiani et al. (2016) proposed a benchmark model for various analyses. The model structure is similar to that of the K&S model in that capital goods firms' customers are only consumer goods firms,

and consumer goods firms only sell to households. The EURACE is a massive model that aims to precisely replicate the characteristics of the Eurozone economy Deissenberg et al. (2008), Dawid and Harting (2012), Cincotti et al. (2010, 2012). The authors of van der Hoog and Dawid (2015) used the EURACE model to analyze the impact of credit and liquidity regulations on the economic growth rate. The Hooga model, similarly to the S&K and CATS models, divides firms into two sectors, namely, capital and consumer goods sectors, with no customer–supplier relationship between firms in the same sector.

3. Sector-Focused Approach

The authors of Hillman et al. (2021) developed the CAB model for analysis of the new coronavirus outbreak and subsequent economic stagnation. They employed a model designed for the corporate sector rather than a macroeconomic approach. Attempts have been made to match the attributes of the firm agent with various real-world firm data characteristics. The following are the main features of the CAB model: (1) The attributes of the individual firm (firm size, production capacity, industry, and financial status) are skewed. (2) Firms are connected through sparse supplier–customer relationships. (3) Firms interact through supplier–customer and credit relationships (accounts receivable, accounts payable, etc.). (4) Firm behavior varies and can be nonlinear based on expectation formation, productivity constraints, and irrational judgments. Thus, the CAB model has the following implications: (1) The structure and interactions among firms amplify or shape the robustness of the demand shocks. (2) Inter-firm relationships and firm statistics influence economic dynamics. (3) Corporate chain failures are rarely the result of a domino effect, but rather of the cumulative effects of multiple shocks and supplier–customer relationships. The authors of Rahman et al. (2021) developed a model for the face mask supply chain network and used it to analyze measures to mitigate the impact of COVID-19 on product manufacturing and supply. The authors of Inoue and Todo (2019, 2020) analyzed the propagation of shock effects through domestic firms' inter-firm supplier–customer relationship networks. Relationship data were used to construct a model in which approximately 890,000 corporate agents were used to form an inter-company network and to study the propagation of shocks from natural disasters and the effects of the lockdown of Tokyo on Tokyo and other areas in Japan. The author of Inoue (2021) extended the model using a WIOT to analyze the impact of shocks on domestic firms' exports and imports.

Instead of firm-level agents, some models subdivide the firm sector into many sub-industries and use industry-level agents. The authors of Otto et al. (2017) analyzed the effect of supply shocks propagating through the supply chain networks in global markets using the model with country-industry-level agents. The authors of Guan et al. (2020) used sector-level agents in global markets to analyze the impact of lockdowns. The authors of Pichler et al. (2020) subdivided 55 industries based on the WIOT and used industry-level agents to analyze demand shocks, supply shocks, and their combinations due to coronal shocks in the U.K.

4. Advantages and Disadvantages of the Two Approaches

Researchers outlined two approaches for analyzing the spread of shocks in the economy using agent-based models; however, both approaches have advantages and disadvantages. The ACE approach has the advantage of analyzing interactions between economic agents. However, its disadvantage is that the model's overall structure is large and complex. Meanwhile, each entity's attributes and behaviors tend to be simplified. As an example of simplification, the model structure used in the representative ACE model, which divides firms into two categories, namely, capital and consumer goods firms, is considered a bottleneck in analyzing the propagation of the impact of economic shocks. This is because capital goods firms produce capital goods solely using labor power and sell them to consumer goods firms. However, in reality, no firms manufacture products solely through the use of labor. Furthermore, because capital goods firms do not use intermediate input materials, they are always on the upwind side of the inter-firm supplier–customer relationship, which may distort the propagation of effects among firms.

The approach that focuses on the corporate sector has the advantage of easily conducting precise modeling in the corporate sector, which is the inverse of the ACE approach. However, its disadvantage is that it cannot capture interactions with other sectors. For example, it is difficult to model the interactions among entities, such as changes in household consumption activities caused by changes in household sentiments that perceive favorable or unfavorable corporate activities, using only the corporate sector.

As explained in the Introduction, there are few researchers making efforts to construct models that combine the strengths of these two approaches. The authors of Delli Gatti and Grugni (2022) developed an agent-based framework characterized by two networks, a credit network connecting banks and firms and a production network connecting upstream and downstream firms, in order to analyze the macro-financial consequences of the disruption of a supply chain. The structure of upstream and downstream firms is similar to the structure of the traditional macroeconomic models with capital goods and consumer goods firms. The authors of Di Domenico et al. (2022) developed a macroeconomic ABM in which the corporate sector is divided into a mining sector that produces non-reusable materials, a recycling sector that produces reusable materials, a capital goods sector, an energy sector, and a final consumer goods sector, and analyzed the conditions under which reusable materials are selected. The basic transaction relationships among sectors are one-way flows of materials, for example, from the capital sector to the mining sector to the recycle sector to the final consumer goods sector (except for the relationship between the energy sector and the capital sector). In this respect, it can be said that this one-way type of relationship is an extension of the relationship between capital and consumer goods firms in conventional macroeconomic ABMs. On the other hand, the relationships in the proposed model can be regarded as two-way types, and researchers believe this is what makes the difference between the two models. The authors of Poledna et al. (2023) developed a very sophisticated ABM for a small open economy utilizing the System of National Accounts, business statistics, and input–output tables in order to forecast macro variables. The business relationships among firms can be bidirectional, which is similar in the model, but differs in the aspect that the business relationships are randomly established at any given point in time, and the business transaction network structure is not maintained, having to be constructed on each occasion accordingly. In Poledna's model, if a particular firm is unable to produce output, other firms in the same industry can cover for it, whereas in the proposed model, the impact of production failure directly affects the production of the client firm.

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