

# Innovation, Demand, and Finance in an Agent Based-Stock Flow Consistent model

Alessandro Caiani<sup>\*§</sup>, Eugenio Caverzasi<sup>§</sup>, Antoine Godin<sup>†</sup>, Luca Riccetti<sup>¶</sup>,  
Alberto Russo<sup>§</sup>, Mauro Gallegati<sup>§</sup>, Stephen Kinsella<sup>†</sup>, and Joseph Stiglitz<sup>‡</sup>

\* Corresponding author: [a.caiani@univpm.it](mailto:a.caiani@univpm.it)

† Kemmy Business School, University of Limerick, Limerick, Ireland

‡ Columbia University, New York, NY, USA

§ Department of Economic and Social Sciences, Marche Polytechnic University, Ancona, Italy

¶ Department of Management, Sapienza University, Rome, Italy

## I. EXTENDED ABSTRACT

We present an **agent based stock flow consistent** macroeconomic model with heterogeneous agents interacting through a decentralized matching process across multiple markets with multiple assets. The model is consistent across both the micro and macroeconomic levels, by providing a detailed, comprehensive, and rigorous accounting of real and financial flows and stocks. We implement the model using a brand new Java programming platform, explicitly designed for AB-SFC models.

Our **java macro agent based** platform JMAB exploits the opportunity of object oriented programming in order to ensure the accounting consistency of any model from the very bottom layer, that is by tracking through generic procedures all the variations in the balance sheets of agents generated by different types of transaction or transfer. Decisions undertaken by individual agents result in variations of their balance sheets which also affect the balance sheets of other agents both directly and indirectly, adding a new layer of complexity to be explored, and we can track these interactions.

We analyze the endogenous emergence of growth, business fluctuations, and financial instability. The model we build explicitly takes into account innovation dynamics, and using JMAB we can analyze the impact of innovation on the structure of production processes, the evolution of industrial market structures, and employment dynamics.

The economy at hand is composed of:

- Households selling their labor to firms, consuming and saving, with their savings being allocated between cash and deposits.
- Firms, divided into consumption and capital firms. Consumption firms produce a homogenous consumption good using labor and capital goods produced by capital firms. Capital firms produce different ‘vintages’ of capital out of labor only and invest in R&D, hiring people to perform this research activity. When innovations are successful, capital firms can produce more productive vintages of capital, starting from the following period. Each capital vintage is characterized by a specific level of productivity.

- A Government sector which hires public workers (as a constant share of the workforce), collects taxes and issues bonds to cover any deficit between current expenditure (wages, interests on bonds and repayment of bonds reaching maturity) and revenue from taxation. Government bonds are purchased by banks.
- Banks, collecting deposits from households, granting loans to firms and buying bonds issued by the Government. Basel III constraints apply so that, at the end of the period, banks may ask for cash advances to the Central Bank in order to restore the mandatory capital adequacy ratio.
- A Central Bank, which issues legal currency, holds banks’ reserve accounts and accommodates banks’ demand for cash advances at a fixed discount rate.<sup>1</sup>

These groups of agents, or sectors, are characterized by bounded rationality and follow (relatively) simple heuristics in an incomplete and asymmetric information context.

During each period of the simulation agents interact on five markets through a common decentralized matching mechanism, following [10]:

- A consumption goods market: households interact with consumption firms;
- A capital goods market: consumption interacts with capital firms;
- A labor market: households interact with government and (both types of) firms;
- A credit market: firms interact with banks;
- A deposit market: households interact and firms with banks,

In each of the markets we implement the following matching protocol, where two classes of agents interact in demand/supply space. One side observes a list of potential

<sup>1</sup>The primary objective of the model is not to analyze the dynamics and stability of public finance, so in the Baseline Scenario we assume that the Central Bank is not allowed to buy government bonds (i.e. a “UE scenario”). Nevertheless, we try to keep the structure of the model open to the implementation of a different scenario in which the Central Bank is part of a consolidated government sector, along with the treasury (i.e. a “USA scenario”).

counterparts and chooses the most suitable partner according to some market-specific criterion.

At the beginning of each period the list of agents on the demand side—households in the consumption market, consumption firms in the capital good market, capital and consumption firms in the labor market, capital and consumption firms in the credit market, households and firms in the deposits market—is randomly shuffled.

Then the first agent in the list observes a random subset of potential partners whose size depends on a parameter  $\chi$  which proxies the degree of imperfect information, and chooses the ‘best’ one: the cheapest counterpart for the consumption interaction, labor and credit markets, the capital vintage with the best trade-off between productivity and price on the capital market, and the bank paying the higher interest rate for the deposit market. After that, the second agent on the list performs the same activity on a new random subset of the updated potential partner list, and so on until we reach the end of the demand side list. The agents on the demand side are ‘deactivated’ when they have fulfilled their demand or if they have not enough liquid resources to buy further. Agents on the supply side are deactivated as soon as they have placed all their orders.

Given this iterative process it might be the case that agents on the demand side end up being supply constrained if the chosen partner does not have enough output to satisfy their demand, or agents on the supply side may not be able to place all their supply orders on the market. In the case of the consumption market, we allow interactions to take place several times during the same period, thus giving the opportunity to agents on the demand side to find new partners in order to fulfil their demand.

As mentioned above the model implements for the very first time in the field of innovation economics stock flow consistency [8] at both the micro- and macro-economic levels, by providing a detailed, comprehensive, and rigorous accounting of real and financial flows and stocks. The aim of the SFC framework is to provide a comprehensive representation of both the real and financial sides through the adoption of rigorous accounting rules based on the quadruple entry principle developed by Morris Copeland [4]. The adoption of an SFC approach will help agent based models to establish themselves as an alternative theoretical paradigm in economic thinking and as a powerful tool for policymakers. A growing number of scholars within the agent based modeling and post-Keynesian schools of thought have argued in favor of AB-SFC models (see [9], [1], [11], [10], [2], [3], see also the EU-funded Eurace Project[5]). The existing literature still provides only a few examples of truly AB-SFC models, characterized by a high degree of heterogeneity concerning both the economic issues addressed and the solutions adopted. This limits their generality, while making it difficult to compare them and to assess their effective consistency. Efforts to embed stock flow consistency in the bottom-up grounded framework of AB models have also proceeded along a number of parallel paths pursuing specific solutions to common problems, rather

than establishing a common set of concepts, rules and tools as we have. One of the objectives of the present work is thus to foster a methodological advance by implementing a brand new Java programming platform, explicitly designed for AB-SFC models. JMAB exploits the opportunity of object oriented programming in order to ensure the accounting consistency of an AB model from the very bottom layer, that is by tracking through generic procedures all the variations in the balance sheets of agents generated by different types of transaction or transfer.

By combining the AB and SFC approaches, we are adding a fundamentally new layer of complexity. In addition to agents’ interactions in shaping individual and aggregate behaviors, we can now model the fact that, in a monetary economy, agents are closely interrelated through a network of interacting balance sheets. Decisions undertaken by individual agents result in variations to their balance sheet, which also affects the balance sheets of other agents, both directly and indirectly. Tracking these relationships is absolutely crucial in order to understand the functioning of our highly financialized economies, and we do this here for the first time in a tractable and scalable manner<sup>2</sup>.

We sketch out the basic structure of our model by verbally describing each agents’ behavioral equations. In each period of the simulation, the following sequence of events takes place:

- 1) *Production planning*: both consumption and capital firms set their desired level of production based on their individual sales expectations in order to attain a target level of inventories, expressed as a share of sales, that they hold as buffer stock in order to face unexpected demand swings (and avoid frustrating customers with undue supply constraints).
- 2) *Pricing*: consumption and capital firms set the price of their output based on a simple adaptive rule. The price is revised downward by a stochastic amount whenever the level of inventories at the end of the previous period is above the target set by the firms, and vice-versa. Capital firms then send a ‘brochure’ to a random subset of consumption firms advertising both the price and the productivity of the capital vintage produced in order to spur production and consumption.
- 3) *Demand for workers*: based on their desired output, firms evaluate the number of workers needed for productive activities. For capital firms this amount depends on labor productivity, while for consumption firms it depends on the productivities of the respective capital vintages employed in the production process at any moment.
- 4) *R&D investment*: capital firms define the desired investment in R&D for the current period. Since we assume that R&D is performed by hiring people to perform research activities, desired R&D investment can be thought of as a desired nominal demand for R&D

<sup>2</sup>We view this feature, as already explained in [2] is crucial in order to analyze the inter-linkages between the real and financial sides of an economic system.

workers, which sums up to capital firms' demand for workers to be employed in production.

- 5) *Investment in capital accumulation*: the desired rate of capacity growth of consumption firms is defined as a positive function of their past profitability, and a negative function of the current debt burden, which is being expressed as the ratio between the overall flow of interest payments on past loans divided by profits. Consumption firms chose the capital vintage to invest in by comparing the price and productivities advertised in the 'brochures' (randomly) received from capital firms. Here we follow a logic similar to that presented in [6]. Consumption firms may also decide to invest in order to replace some of the old vintages in their stock, even though they might still be working, if the advantage brought about by the new vintage in terms of lower expected unit costs of production is higher than the cost of purchasing the new vintage (that is, we have a 'payback period rule');
- 6) *Credit demand*: in accordance with the dynamic trade-off theory of firms' capital structure (see [7]) firms' credit demand at time  $t$  depends on their net worth and their leverage target. In each period, this leverage target is adaptively revised according to each firm's debt burden and past sales.
- 7) *Credit supply*: banks set their total loan supply based on their expected variation in reserves in order to attain, by the end of the period, the mandatory capital adequacy ratio (CAR, hereafter) without having to refinance through the central bank's liquidity auctions. The interest rate on loans depends on a bank-specific component and a borrower-specific component: the bank-specific component is revised adaptively according to the gap between past period desired and realized credit supply. When positive, the interest rate is lowered to make banks' loans more attractive for borrowers, and vice-versa when the gap is negative. The borrower-specific component proxies firms' perceived reliability, and it is determined as an increasing function of the borrower's leverage. Banks and firms then interact in the credit market through the matching mechanism specified above.
- 8) *Wages and labor market interactions*: Workers adapt their asked, or market, wages according to whether they were employed or not during the previous periods following [9]: if over the year (assumed to be four periods) they have been unemployed for more than two quarters, they lower the asked wage by a stochastic amount. In the opposite case they increase their asked-for or market wage, provided that the aggregate rate of unemployment is sufficiently low. The government hires a constant number of (randomly chosen) workers. Workers still unemployed then interact with firms in the labor market through the matching mechanism specified above.
- 9) *Production*: capital and consumption firms produce their output, the actual amount being potentially different from the desired one if labor (and capital, in the case of consumption firms) constraints apply.
- 10) *R&D activity*: capital firms perform R&D. The probability of success in each period is defined as a positive function of invested resources. In the case of a successful innovation, a new level of productivity is drawn and the innovation (i.e. the higher level of productivity) is embedded in capital goods produced from the following period onward.
- 11) *Consumption*: households consume out of income and wealth with fixed propensities. They interact with consumption firms through the matching mechanism specified above.
- 12) *Capital goods market*: The actual transaction takes place once the matching mechanism between agents on the demand and supply sides is finished, and with consumption firms having already decided the type of capital they want to buy. If after this matching process the consumption firms remain financially constrained, or if supply constraints apply, they might end up with less capital than desired, forcing an automatic need for bank financing of their activities.
- 13) *Loans repayment and interests*: firms pay interest on loans, and repay a (constant) share of the principal.
- 14) *Taxes*: taxes on profits (of firms and banks), income (of households), and wealth are paid to the government.
- 15) *Government bonds interests and repayment*: the government pays interest on bonds held by banks and repays bonds at maturity.
- 16) *Deposits market interaction*: banks set the interest rate on deposits following an adaptive rule, which mirrors the rule used to determine the bank-specific component of loans and interest rates. When the gap between desired and realized credit supply in period  $t - 1$  is positive, banks will tend to lower the interest rate on deposits by a stochastic amount in order to maintain their profit margin, which depends on the spread between interest charged on loans and interest paid on deposit. Otherwise, they will increase the interest rate in order to attract more deposits. Banks then interact with households and with firms through the matching mechanism explained above. We assume households maintain a constant share of their wealth in cash, with the remainder being held in the form of deposits. We assume firms deposit all their cash revenues into their deposit accounts, reflecting the reality that firms holding of cash is negligible compared to their stock of deposits.
- 17) *Bonds purchases*: the government issues new bonds to cover any deficit between expenditure (for wages, interest payments on the stock of debt and repayment of bonds which have reached maturity) and revenues (taxes). In the simplest scenario, we assume that the interest rate on bonds is fixed and banks buy all newly issued bonds, in proportionally to their relative size. Banks pay bonds by making a transfer from their reserve account at the Central Bank to the government's account, asking for cash advances from the central banks if

needed. We assume the repo rate fixed and equal to the interest rate on bonds.

- 18) *Cash Advances*: banks ask the Central Bank for cash advances when they need to fulfil mandatory CAR constraints.

Firms may default during the simulation when their net wealth turns negative after having paid interests or principal repayments on loans, or taxes. The default by a firm implies a loss for banks whose loans have not been completely repaid yet. This loss in turn may result in the bankruptcy of some banks in exceptional cases. This situation must be carefully managed to ensure the Stock Flow Consistency of the model. We assume that a bank in default is taken over by the wealthiest bank in business at time  $t$ , which inherits all its assets and liabilities. In order not to induce a loss for the acquiring bank (which would make the operation unreasonable), deposits held at the defaulted firm are lowered in the measure required to restore the parity. In the simplest case this acts as a bail-in type of buffer stock. The shock is absorbed by depositors (households and firms), the loss being distributed across deposits proportionally to their original amount.

The investment by capital firms in R&D triggers a process of ‘Schumpeterian competition’ between both capital and consumption firms. The capital firms compete by producing capital goods which entail different levels of productivity, while the consumption firms compete in an homogeneous good market trying to lower their production costs through capital investment in newly created vintages. The role played by ‘selection mechanisms’ operating in both markets leads to the default of some firms. Capital firms may default as a consequence of bad innovative performances, which make their output less attractive for consumption firms. On the other hand, consumption firms may default if, through the matching mechanism, they come to invest in less profitable vintages. In both cases strong cumulative effects are at work: capital firms which are fast enough in obtaining innovations may gain an advantage over their competitors resulting in them being more profitable, investing more in R&D, and thus enhancing their probability of achieving further innovations. Similarly, consumption firms that invest in the most profitable capital vintages (for given prices and productivities) may grow faster and invest more in the future periods, further increasing their productive capacity and improving their production process. In turn, these defaults imply a non-performing loan for banks who granted credit to defaulted firms, that is a loss on banks’ balance sheets. This may affect banks’ credit supply and, in some extreme case, it may even result in a bank’s bankruptcy. Shocks related to the endogenous default of firms may thus propagate in the economy through contagion effects across agents’ balance sheets, possibly generating a cascade of failures which affects employment and demand dynamics. Furthermore, by affecting labor productivity in the consumption sector, technological innovation may exert an impact on labor demand by consumption firms even in the absence of traumatic events, thus possibly affecting also demand patterns. In turn,

a weak demand can induce a drop in firms’ sells, depressing R&D investment and slowing down innovation dynamics.

In conclusion, this paper analyses the endogenous emergence of growth, business fluctuations, and financial instability in an agent based stock flow consistent framework which explicitly takes into account innovation dynamics, analyzing their impact on the structure of production processes, the evolution of industrial market structures, and employment dynamics. The adoption of an AB-SFC approach helps us study the effects of technological change on both the real and financial economy by tracking the flows of funds resulting from the rise of innovations in the system in a novel and comprehensive framework. The model aims to build a bridge between the Keynesian and Schumpeterian schools of thoughts by studying the inter-dependence between supply and demand factors in shaping business fluctuations. s

## REFERENCES

- [1] D. Bezemer, “The economy as a complex system: the balance sheet dimension,” *Advances in Complex Systems*, vol. 15, 2012, p.22.
- [2] A. Caiani, A. Godin, and S. Lucarelli, “Innovation and finance: a stock flow consistent analysis of great surges of development,” *Journal of Evolutionary Economics*, vol. 24, 2014, pp. 421-448.
- [3] E. Caverzasi and A. Godin, “Stock-flow consistent modeling through the ages,” *Levy Economic Institute Working Paper Series*, 2013, No. 745.
- [4] Morris A. Copeland, “Social Accounting for Moneyflows,” *The Accounting Review*, vol. 24(3), 1949, pp. 254-264.
- [5] C. Deissenberg, S. Van Der Hoog, and H. Dawid. “EURACE: A massively parallel agent-based model of the European economy.” *Applied Mathematics and Computation* Vol. 204(2), 2008, 541-552.
- [6] G. Dosi, G. Fagiolo, and A. Roventini, “Schumpeter meeting Keynes: A policy-friendly model of endogenous growth and business cycles,” *Journal of Economic Dynamics and Control*, vol. 34 no. 9, 2010, pp. 1748-1767.
- [7] M.J. Flannery MJ and K.P. Rangan, “Partial adjustment toward target capital structures,” *Journal of Financial Economics*, vol. 79 no. 3, 2006, pp. 469-506
- [8] W. Godley and M. Lavoie, *Monetary Economics An Integrated Approach to Credit, Money, Income, Production and Wealth*, Palgrave MacMillan, New York; 2007.
- [9] S. Kinsella, M. Greiff, and E. J. Nell, “Income Distribution in a Stock-Flow Consistent Model with Education and Technological Change,” *Eastern Economic Journal*, vol. 37, 2011, pp. 134-149.
- [10] L. Riccetti, A. Russo, and M. Gallegati, “An agent-based decentralized matching macroeconomic model,” *Journal of Economic Interaction and Coordination*, 2014, forthcoming.
- [11] P. Sepecher, “Flexibility of Wages and Macroeconomic Instability in an Agent-Based Computational Model with Endogenous Money,” *Macroeconomic Dynamics*, vol. 2, 2012, pp. 284-297.

## II. ACKNOWLEDGEMENTS

Funding from the Institute for New Economic Thinking is gratefully acknowledged.