A Hybrid AB-SFC Macroeconomic Model with an explicit distribution of income and wealth

Michele Ciruzzi*

21st March 2023

Recent developments in Post-Keynesian macroeconomics have found in Stock-Flow Consistent models a general framework to enforce the macroeconomic accounting identities in the models. These models are sometimes extended to include micro-foundations (or a microeconomic description) through the use of Agent-Based Models. But despite the progress and the diffusion of AB-SFC models in the last ten years, very few models can replicate the fat-tail distribution of income and wealth observed empirically. Instead, they usually rely on a Kaleckian distinction between workers and capitalists or a segmented labour market (for example low-, medium- and high-skilled workers). This model aims to reproduce a fat-tail distribution in income and wealth, in addition to other stylized facts, by differentiating workers by their skills and the capital goods used in production by their productivity and the skills required to use them. A realistic distribution of income and wealth allows bringing closer this strain of literature with the literature on income and wealth inequality since it makes measuring indexes like Gini or the top5/bottom50 ratio possible. The model includes endogenous innovation and credit rationing as previous models in the literature. Households' consumption is expressed in material terms (i.e. the amount of goods consumed), rather than in monetary value, to be able to differentiate the goods consumed and better characterize the behaviour of low-income households in a future version of the model, relying on empirical stylized fact and the interpretative framework of the Foundational Economy. Furthermore, the model is designed to compare different welfare policies, like minimum wage, minimum income, Universal Basic Income, Universal Basic Services or Job Guarantee programs, and different political orientations in public policies, like the austerity principles of the '10s, a Keynesian demand-led public spending or an entrepreneur state. At the time of writing this abstract, the model has been completely outlined on paper but no numerical simulation has been performed yet.

1 Introduction

In recent years Stock-Flow Consistent (SFC) models have been recognized as a valuable tool to model macroeconomics (Nikiforos & Zezza, 2017). Particularly, they can represent the financial

side of the economy, which has been recognized as a necessary feature to model after the financial crisis of the 00s.

Those models are aggregate models which can neither describe microeconomic dynamics and behaviours nor, if it is considered necessary, provide a microfoundation for the model. Agent-Based Models (ABMs) have been used to add a microeconomic description to the macroeconomic model provided by the SFC framework (Caverzasi & Russo, 2018; Dosi & Roventini, 2019).

But in the SB-SFC models literature, very few papers explore the conditions to model a realistic (i.e. fat-tail) distribution of income and wealth among households (e.g. Dafermos & Papatheodorou, 2015; Kinsella et al., 2011), often relying on a Kaleckian framework which studies the distribution between wages and profits (e.g. Dosi et al., 2013) or a segmented labour-market (e.g. Caiani et al., 2019).

Modelling personal income and wealth distribution is a needed step to close the gap between this strain of post-Keynesian literature and the literature on inequality pioneered by Atkinson, Piketty, Zucman and Saez, allowing for example to measure the evolution of inequality indexes (like Gini or the Top5/Bottom50) through time or policies changes.

Some choices in the model are dictated by its long-term goals, specifically comparing disruptive welfare policies (Universal Basic Income, Universal Basic Service, Job Guarantee, …) and focusing on the different consumption patterns between high- and low-income households, including different compositions of the consumption bundle, the relevance of publicly provided goods and services (including infrastructures) in the consumption bundle, following the Foundational Economy framework (Arcidiacono et al., 2018), the incidence of unpaid domestic and care work on the work provided by individuals in the household, especially from a gender perspective.

Finally, the model is inspired more by west-European economies (particularly Italy) rather than by north-American ones.

2 General Hypothesis

To simplify the model a close single-country economy is assumed. This is a common hypothesis for SFC models (and macroeconomics in general) because an open economy does not preserve the balance of flows in the model. So, to preserve the consistency of the model the only alternative is to model a multi-countries system, each with its own dynamics. It is worth keeping in mind that this hypothesis prevents to model to replicate economic dynamics strongly dependent on international trade, like the export-led growth path.

The microeconomic behaviour of the agent is modelled mostly using adaptive expectations, focusing on the variation of behaviours (as desires or expectations) with regard to the previous period. Exploiting this, to smooth the dynamics of the model each period represents a month (a small amount of time compared to other models) to keep the variations small.

The model includes the six sectors: the Households ($\mathbf{H}$), the Firms which produce consumption goods ($\mathbf{F}_{\mathcal{C}}$), the Firms which produce Capital goods ($\mathbf{F}_{\mathcal{K}}$), a consolidated (i.e. aggregated) Banking and financial sector (the Bank, $\mathbf{B}$), the Government ($\mathbf{G}$) and the Central Bank ($\mathbf{C}$). Households and Firms constitute the Agent-Based part of the model.

The model comprises two kinds of real assets: Capital Goods ($\mathcal{K}$) and Consumption Goods ($\mathcal{C}$). Capital Goods are durable and Consumption Goods are homogeneous.

The model includes five different financial assets. Bank Deposits ($\mathcal{D}$) of Households and Firms, which are not interest-bearing. Loans ($\mathcal{L}$) issued by the Banks to Firms, which interest rate is Firm-specific and fixed by the Bank. Bank Shares ($\mathcal{S}$) held by Households, which interest rate is fixed each period by the Bank. Banks Reserves and Government Account at the Central Bank ($\mathcal{R}$), which are not interest-bearing. Government Bonds ($\mathcal{B}$) held by Bank and Central Bank, and which interest rate is fixed by the Central Bank.

3 Matrices

3.1 Balance Sheet Matrix

	H	**F**$_\mathcal{C}$	**F**$_\mathcal{K}$	**B**	**G**	**C**	Tot.
$\mathcal{D}$	$+\mathcal{D}_\mathbf{H}$	$+\mathcal{D}_{\mathbf{F}_\mathcal{C}}$	$+\mathcal{D}_{\mathbf{F}_\mathcal{K}}$	$-\mathcal{D}$			0
$\mathcal{S}$	$+\mathcal{S}$			$-\mathcal{S}$			0
$\mathcal{L}$		$-\mathcal{L}^{\mathbf{F}c}$	$-\mathcal{L}^{\mathbf{F}\kappa}$	$+\mathcal{L}$			0
$\mathcal{B}$				$+\mathcal{B}_\mathbf{B}$	$-\mathcal{B}$	$+\mathcal{B}_\mathbf{C}$	0
$\mathcal{R}$				$+\mathcal{R}_\mathbf{B}$	$+\mathcal{R}_\mathbf{G}$	$-\mathcal{R}$	0
$\mathcal{K}$		$+p_\mathcal{K}\mathcal{K}_{\mathbf{F}_\mathcal{C}}$	$+p_\mathcal{K}\mathcal{K}_{\mathbf{F}_\mathcal{K}}$				$+p_\mathcal{K}\mathcal{K}$
Tot.	$+V_\mathbf{H}$	$+V_{\mathbf{F}_\mathcal{C}}$	$+V_{\mathbf{F}_\mathcal{K}}$	$+V_\mathbf{B}$	$+V_\mathbf{G}$	$+V_\mathbf{C}$	$+p_\mathcal{K}\mathcal{K}$

V is the net worth of the sector.

3.2 Transactions Matrix

	H	**F**$_\mathcal{C}$	**F**$_\mathcal{K}$	**B**	**G**	**C**	Tot.
Consumption	$-p_\mathcal{C}\mathcal{C}_\mathbf{H}$	$+p_\mathcal{C}\mathcal{C}$			$-p_\mathcal{C}\mathcal{C}_\mathbf{G}$		0
Investment		$-p_\mathcal{K}\mathcal{K}_{\mathbf{F}_\mathcal{C}}$	$+p_\mathcal{K}(\mathcal{K}-\mathcal{K}_{\mathbf{F}_\mathcal{K}})$				0
Wages	$+W$	$-W^{\mathbf{F}c}$	$-W^{\mathbf{F}\kappa}$				0
Taxes	$-T$				$+T$		0
Transfers	$+M$				$-M$		0
F Profits		$-\Pi_\mathbf{B}^{\mathbf{F}c}$	$-\Pi_\mathbf{B}^{\mathbf{F}\kappa}$	$+\Pi_\mathbf{B}$			0
C Profits					$+\Pi^\mathbf{C}$	$-\Pi^\mathbf{C}$	0
$\mathcal{S}$ Interests	$+r_\mathcal{S}\mathcal{S}$			$-r_\mathcal{S}\mathcal{S}$			0
$\mathcal{L}$ Interests		$-r_\mathcal{L}\mathcal{L}^{\mathbf{F}c}$	$-r_\mathcal{L}\mathcal{L}^{\mathbf{F}\kappa}$	$+r_\mathcal{L}\mathcal{L}$			0
$\mathcal{B}$ Interests				$+i\mathcal{B}_\mathbf{B}$	$-i\mathcal{B}$	$+i\mathcal{B}_\mathbf{C}$	0

4 Sectors

4.1 Households

In this model, the core agents (consumer, worker, capitalist) represent a household rather than a single individual. This is a very common approximation in economics and I think it is reasonable as long as we are not going into modelling education paths and care work, where the gender asymmetries become very relevant.

Each agent is characterized by an education level assigned when it enters the simulation replacing a retired agent inheriting their wealth, and gains experience when working in the same sector (Capital/Consumption) without an employment gap. The education level is assigned with a probability related to the inherited wealth and provides the starting skill level. Skills s evolve like in Dosi et al. (2018), which means $s_t = (1 + \phi)^\delta s_{t-1}$ where $\delta = 1$ if the household is employed in the same sector of the previous time step, $\delta = 0$ if the household is still employed but in a different sector, $\delta = -1$ if the household is unemployed.

Households face two choices: if work and which proportion of their income they should consume.

Households flows' balance is $I = W + M + rS = C + T + \Delta S + \Delta D$. I assume, as a heuristic, that Taxes (T) and Transfers (M) can be approximated as constant from the previous period. Additionally, I assume that desired Deposits (D) at the end of the period are a fraction of the

desired consumption ($C = \langle p_G \rangle G$) as insurance against unexpected increases in prices or unemployment[1] ($D = \rho\, C$, $\rho > 0$). Subtracting two consecutive periods and ignoring second-order differences, the in-flow income becomes $\Delta I = \Delta W + \Delta r S + r \Delta S$, and calling η the marginal propensity to consume it becomes $\eta \Delta C \approx \Delta W + \Delta r S + r \Delta S$. Fixed the income level I we can write $0 = \Delta C + \Delta D + \Delta S = (1 + \rho)\Delta C + \Delta S$ to express the choice the household faces between consumption and saving. Putting these together we find $\eta \Delta C \approx \Delta W + \Delta r S - r(1 + \rho)\Delta C$ and so $\Delta C \approx \frac{\Delta W + \Delta r S}{\eta + r(1+\rho)}$, which provides an adaptive rule for monetary consumption.

To translate this in material terms I introduce the material consumption of consumption goods G. We have $\Delta C = \Delta(pG) \approx \Delta(p)G + p\Delta G \approx p(\pi G + \Delta G)$. We can finally rewrite $\Delta G = \frac{\Delta W + \Delta r S}{p(\eta + r(1+\rho))} - \pi G$

ΔW can be approximated by $w W_{t-1}$ where w is the average rate at which wages for the given skill level are increased in the last year[2]. Δr is communicated by the Bank before the agent has to choose between consumption and saving. η is calibrated from empirical data as an exponential or Pareto distribution as $\eta(\frac{S}{p}, \frac{W}{p})$, where the price is used to get a-dimensional values (Carroll et al., 2017; Fisher et al., 2020).

From this relation, we can model the two choices.

First, a household exits from the labour market if the loss of the wage can anyway grant an increase in consumption, i.e. $\Delta r S - p\pi(\eta + r(1 + \rho))G > W$. Similarly, it re-enters the labour market if the expected salary (i.e. the average salary given the skill level) prevents a loss of consumption, i.e. if $\Delta r S - p\pi(\eta + r(1 + \rho))G < 0$ and $W + \Delta r S - p\pi(\eta + r(1 + \rho))G > 0$.

Second, each household sets the desired total consumption as $\mathbb{E}(G) = G + \Delta G$ (using G from the previous period). From which follows $\mathbb{E}(C) = p(1 + \pi)\mathbb{E}(G)$, $\mathbb{E}(D) = \rho p(1 + \pi)\mathbb{E}(G)$ and $\Delta S = D + (1 + w)W + M - (1 + \rho)\mathbb{E}(C)$, where D is the value of the deposit at the end of the previous time step.

4.2 Firms

Firms are characterized by their position in the supply chain (either Capital or Consumption).

In the case of rationed credit, Firms first pay the salaries of workers, then they pay the salaries of researchers, then they acquire new machinery and finally repay the Bank of the Loans contracted.

4.2.1 Consumption Firms

Noted S the number of goods sold in the previous period, each Firm sets the desired production as $\mathbb{E}(G) = k(1 + g - \pi)S$, where g is the GDP growth rate.

The maximum output of the available machinery is defined as $B = \sum_{k \in K} \beta_k$. Each Firm set a desired potential output $\mathbb{E}(B) = \frac{1}{u^*}\mathbb{E}(G) + \delta B$, where δ is the depreciation rate of capital and u^* is the target capacity utilization rate. From this follows that $\Delta B = \max(\frac{\mathbb{E}(G)}{u^*} - (1 - \delta)B, 0)$ and the expected investment in monetary units is $\mathbb{E}(I) = p_K \frac{\Delta B}{\langle \beta \rangle}$.

The expected expense for salaries is $\mathbb{E}(W) = \frac{\mathbb{E}(G)}{\langle \beta \rangle}\langle w \rangle$, where w are the individual salaries paid.

Loans are required for an amount equal to $\mathbb{E}(L) = \max(k(\mathbb{E}(I) + \mathbb{E}(W)) - D, 0)$.

The markup is set equal to $\mu = \mu_{t-1}(1 + \theta\frac{S_{t-1}}{G})$ after that the production happened.

Called U the balance of flows in the period before distributing profits and D the amount of deposits in the same moment, each firm distributes profits $\Pi = kU\frac{D}{C}$, where $C = I + W$ in the period.

4.2.2 Capital Firms

Capital Firms produce their own machinery, creating a system of two simultaneous equations to determine the desired output. We avoid the problem approximating $\mathbb{E}(B) = \frac{k(1+g-\pi)}{u^*}S + \delta B$, and $\mathbb{E}(K) = k(1+g-\pi)S + \Delta B - K$, where K are the unsold capital goods from the previous period. The machinery produced for own use is kept separate from those to be sold.

Additionally, Capital Firms perform research to improve the machinery they sell. They aim to employ a number of researchers $\mathbb{E}(R) = R(1 + \frac{k}{S}\frac{\Pi}{\langle w_R \rangle})$ where $\langle w_R \rangle$ is the average salaries of the employees with $\sigma \geq \sigma^*$.

Finally, we note that $I = 0$ and so $C = W$.

4.3 Bank

Bank agent represents the aggregate banking sector.

Bank is required to maintain both a liquidity ($\Lambda = \frac{R}{D}$) and a capital ratio ($\Gamma = \frac{V}{L}$).

Liquidity is obtained, in case of necessity, by selling Government's Bonds to the Central Bank.

Bank fixes the interest rates on Bank Bonds as $r_S = (1 - \tau_S)(i + \lambda(\Gamma - \Gamma^*))$, where i is the Central Bank interest rate and τ_S is the constant tax rate on financial income. In this model the Bank does not distribute profits and can access all the needed liquidity from the Central Bank, making the liquidity requirement a tautology and needed a way to avoid excessive capitalization. So, it is not possible to have $r_S(\Lambda)$ (because it will be constant) and to make $r_S(\Gamma)$ approximate a profit distribution, without in a bond-like market (rather than a stock-like ownership model).

It also chooses when granting loans to Firms (based on the balance sheet of the applicant) and fixes a different interest rate for each loan. The duration of Loans is fixed. Bank is willing to provide loans to a firm F up to $\hat{l} = \min(\chi_0(D^F + pK^F) - L^F, \max((\chi_1 N_F)^{-1}L(\frac{\Gamma}{\Gamma^*} - 1), 0))$, at a firm-specific interest rate $r_L^F = i + \gamma_1(\Gamma - \Gamma^*) + \gamma_2(\frac{L^F}{V^F}) - \gamma_3(\frac{\Pi^F}{L^F})$. These relations account for the fulfilment of the capital requirement for the Bank and the presence of sufficient collaterals on the Firm side.

4.4 Government

Government fixes the public expenditure. It additionally collects taxes and pays unemployment benefits. It determines the amount to be transferred to Households (both as monetary and non-monetary, as Essential Goods).

When liquidity is needed, Government emits Bonds and sells them at will to the Central Bank.

As an approximation, fiscal policy is kept constant during the simulation and taxes are collected only from the Household sector during the transactions. Particularly, the model includes four taxes: a VAT on the purchase of consumption goods (τ_G); a flat financial income tax on distributed interests on Bank Bonds (τ_S); a progressive income tax computed as $T_W(W) = W \max(\tau_M \tanh(\tau_F(\frac{W}{p} - \tau_T)), 0)$; an inheritance tax on wealth with a constant rate (τ_I).

Fixed unemployment benefit $U_{t+1} = \gamma \max(W, U)$ is paid to those who have not exited the job market and are not employed.

Each period government buys Consumption goods which distribute to the Households. Particularly each Household receives an amount of Consumption goods equal to $G^G = ((1 - q_0) + q_0 e^{-q_1 \frac{V}{p}})\hat{G}$.

We define g as the growth rate of the GDP (measured as Government and Households consumptions, including VAT, plus the variation in Capital stock, noted as Y) in the previous periods, $M = \sum_H U$ and $G = \sum_H G^G$.

Assuming a Maastricht-like scenario in which Government has a target deficit δ to achieve, the expected balance of the next period can be written as $\delta Y(1 + g) = (1 + \pi)(\mathbb{E}(G) + M) + iT_B(1 + \frac{1}{T^G}\delta Y) - (1 + g)(1 + \pi)T$ where it is assumed that expenses for unemployment benefits

are approximately constant, T are the taxes raised, T_B the stock of Government bonds held by the Bank and T^G is the total stock of Government Bonds.

Then, $\mathbb{E}(G) = (1+g)T + \frac{1+g}{1+\pi}(1 - i\frac{T_B}{T^G})\delta Y - \frac{i}{1+\pi}T_B - M$, from which it is possible to write an adaptive rule for Government demand which aims to match the target deficit as $\Delta \hat{G} = q_2 \frac{\mathbb{E}(G)-G}{pN^H}$, where N^H is the number of Households agents.

4.5 Central Bank

In the model the role of the Central Bank is to fix the Government's Bonds interest rate according to a Taylor rule $i = \pi + \alpha_1(\pi - \pi^*) + \alpha_2(c - c^*) - \alpha_3(u - u^*)$, where π is the inflation rate, c is the capacity utilization measured as the fraction of capital goods used in production, u is the unemployment rate computed among those who have not voluntarily exited the job market, and starred variables are the targets.

Additionally, it passively buys and sells Government Bonds on request to the Bank and the Government. Reserves do not grant interests.

In other words, the Central Bank is a lender of last resort for the Government, which then has no accounting limits to spending.

5 Real Assets

5.1 Consumption Goods

Consumption Goods represent all the consumption (goods and services) of Households and are homogeneous and non-durable.

5.2 Capital Goods

Capital goods are characterized by their productivity β and the minimum skill level required to operate them σ. The production happens according to a Leontieff-like function in which one worker with at least σ skill can operate a single capital good getting β goods as output[3]. Each period they have a fixed probability to break and disappear from the model, equal to $\delta = \langle N \rangle^{-1}$, where $\langle N \rangle$ is the expected life of the machinery.

6 Financial Assets

6.1 Deposits

Deposits represent liquidity for Households and Firms and are not interest-bearing. Bank satisfies any transaction as long as the balance of the account remains positive.

6.2 Bank Bonds

Bank Bonds are sold and bought at their nominal value and do not expire. Bank satisfies every transaction, as long as the accounts remain positive. Households can buy or sell Bank Bonds only at the beginning of each period. At the end of each period, interests are paid, according to the rate fixed by the Bank at the beginning of the period.

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[3]It is possible that to balance the model, the output needs to be β consumption goods or $b\beta$ capital goods.

6.3 Loans

Loans are issued by the Bank to a specific Firm. They have a fixed duration during which an equal share of capital is repaid plus the interest on the remaining debt. Interests are fixed by the Bank at a different value for each Firm at the time of emission.

6.4 Government Bonds

Government Bonds are sold and bought at their nominal value and do not expire. Central Bank satisfies every transaction. Bank can buy Government Bonds only at the beginning of each period. At the end of each period, interests are paid only to the Bank, according to the rate fixed by the Central Bank at the time beginning of the period.

6.5 Reserves

Reserves represent liquidity for Bank and Government and are not interest-bearing. Central Bank satisfies any transaction as long as the balance of the account remains positive.

7 Dynamics

7.1 Consumption Goods market

Each Household sees χ_C Consumption Firms χ_C times, each time it buys $\frac{\mathbb{E}(G) - G^G}{\chi_C}$ at the lowest possible price until it matches the desired consumption or ends liquidity.

7.2 Capital Goods market

Each Consumption Firm sees χ_K Capital Firms χ_K times (including the last one from which it has bought), each time it buys $\frac{\Delta B}{\chi_C}$ machineries choosing the one with the lowest value of $\beta p_C - \langle w_\sigma \rangle - \frac{p_K}{\langle N \rangle}$ until it matches the desired quantity or ends liquidity.

7.3 Labour market

Households are employed by a Firm until they are fired, they chose to exit the job market or they accept an offer from another Firm.

Firms can fire workers only when profits turn negative. In that case, Firms fire workers until the number of workers reaches $u^* K$. Additionally, in the case the Firm is not able to pay a worker, they is fired. In both cases, Firms start to fire those with lower skills.

Firms match each employed worker with the most productive machinery they can use, starting with those with higher skills. For this purpose, a researcher is treated like a worker assigned to a machinery with productivity σ^*. Then the current potential output (as the sum of the productivity of the used machinery) is computed and vacancies are filled starting from the most productive unused machinery. All research vacancies are filled if possible. For each vacancy, the Firm sees χ_L workers which have the required skills and earn less than the average salary in the model for the skill level. The Firm employs the one with the higher skills offering the average salary in the model for the skill level.

Each vacancy is filled once and new vacancies are not filled.

7.4 Retirement and inheritance

When a Household reaches a certain age it is considered retired and is replaced by a new agent in the model which inherits their (taxed) wealth and enters the simulation with a random skill level proportional to the inherited wealth, and a random age proportional to the skill level.

7.5 Non Performing Loans

In the case a Firm is unable to repay the principal of a loan or to pay the interest, the unpaid sum is added to the import of the loan and the duration is increased by one period. Additionally, the loan is marked as non-performing.

7.6 Bankrupt

Once the net value of a Firm becomes negative the Firm declares bankruptcy, fires all the employed households and loose all the financial assets (loans and deposits). It is "replaced" by a new firm which inherits the capital stock.

7.7 Innovation

Each Capital Firm can achieve an innovation each period with a probability $p = e^{-\xi R}$ where R is the number of employed workers not assigned to a Capital Good with skills at least $sigma^*$.

If the innovation is achieved the Capital Goods produced by the Firm increase its productivity $\Delta\beta \propto \text{Beta}(1, b_1)$ and modify the required skills as $\Delta\sigma \propto (\Delta\beta - k\text{Beta}(1, b_2))$.

8 Model steps

  A Statistics are computed at the relevant frequency
  B Agents variables independent from other agents' decisions are updated
  C [QUARTERLY] Central Bank sets the Government Bonds interest rate
D.0 Bank sets the interest rate on Bank Bonds
D.1 Bank buys Government Bonds to reach the liquidity requirement
E.0 Households set desired consumption and savings
E.1 Firms set desired output and investment
F.0 Households acquire Bank Bonds
F.1 Firms ask the Bank for loans
  G Labour market and wages payment
  H Production and price setting
  I Innovation
L.0 Government pays unemployment benefits
L.1 Government buys and distributes Consumption Goods
  M Households Consumption Goods market
  N Capital Goods market
O.0 Firms repay loans and interests
O.1 Government pays interest on Bonds to the Bank
  P Firms distribute dividends
  Q Bank pays interests on Bonds
R.0 [YEARLY] Income taxes are arbitraged
R.1 Capital depreciation

9 Equations

10 Parameters

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