Income distribution, productivity growth and workers' bargaining power in an agent-based macroeconomic model*

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Abstract
We investigate the effect of labor productivity growth and workers' bargaining power on income distribution in a new agent-based macroeconomic model inspired by the post-Keynesian literature. Its main novelties are a wage bargaining process and a mark-up adjustment rule featuring a broader set of dimensions. The former allows nominal wages to be endogenously determined by interactions involving firms and workers, which are mediated by workers' bargaining power. The latter assumes that firms also consider their position relative to workers (through their unit costs) to set their mark-up rates, thus linking the evolution of nominal wages in the bargaining process and labor productivity growth to the functional income distribution. This has implications for the personal income distribution through a three-class structure for households. The model reproduces numerous stylized facts, including those concerning the income distribution dynamics. Our results show the importance of the interaction between workers' bargaining power and productivity growth to the dynamics of income inequality and to its relationship with output. This leads to a policy dilemma between promoting productivity growth and improving income equality which can, nonetheless, be attenuated by combining policies and institutions that sustain workers' strength with policies that stimulate innovation and productivity growth.
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1 Introduction

In the past decades, income inequality has worsened in numerous countries (Atkinson, 1970, Baker et al., 2019, ILO, 2008, Mohun, 2014, Piketty and Saez, 2006, Stockhammer, 2017). There are

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many factors that have been pointed out as driving this dynamics, one of which being the increasing wage-productivity gap. In the case of the U.S., for instance, numerous authors draw attention to a contrast between fairly stagnant real wages and the continuous labor productivity growth (Karanassou and Sala, 2010, Mohun, 2006), which has been associated with increasing mark-up levels and lower wage shares (De Loecker et al., 2020). Indeed, since productivity growth can reduce unit production costs, it is associated with higher mark-up rates when not entirely passed-on to prices. Nevertheless, this process is also affected by institutions that protect workers in the labor market, which form a countervailing force. In fact, the effect of productivity growth on income inequality became more evident when it was combined with institutional changes in the labor market that shifted power towards employers (Bivens and Mishel, 2015, Mishel and Bivens, 2021). Therefore, while productivity growth provides the *potential* for changes in the income distribution, its *actual* effect is mediated by the labor market and, in particular, the relative power of employers *vis-à-vis* workers.

The dynamics of the functional income distribution generated by these forces also entails implications for the personal income and wealth distributions. Indeed, while a higher profit share has a direct effect on inter-class inequality as income becomes more concentrated in rich households (Wolff and Zacharias, 2013), there is also a composition effect because profits tend to be more unequally distributed than wages (Daudey and García-Peñalosa, 2007). Additionally, as a higher personal income inequality is associated with increases in the wealth inequality, the mechanisms driving the former can be relevant to the dynamics of the latter (Tippet et al., 2021).

In order to further investigate the interplay between productivity growth and workers' bargaining power, we build a novel agent-based macroeconomic model. Our main objective is to provide a more encompassing theoretical framework that incorporates the class conflict over the income distribution in a neo-Kaleckian approach (Rowthorn, 1977). The proposed extended framework allows this conflict to be influenced by the extent to which firms take advantage of productivity growth and to which workers' bargaining power affects the nominal wage dynamics. The combination of these features of the model means that workers' and firms' strengths endogenously affect the wage share, thus offering new insights into how technological innovation and labor strength affect inequality. In this sense, the model follows the tradition in agent-based macrodynamic models that aims to reproduce macroeconomic features that emerge from decentralized interactions among heterogeneous agents in a bottom-up approach (Dawid and Delli Gatti, 2018). In addition to reproducing a broad range of stylized facts at the macro and micro levels, a key feature of the model is the reproduction of empirical regularities regarding the income distribution dynamics, which indicates that the model structure is well-suited for our purpose. Our experiments explore the interplay between productivity growth (captured by the capital goods firm's innovation capabilities) and workers' strength (captured by their bargaining power in the wage setting process) and its effect on the functional and personal income distributions. In line with recent empirical investigations (Blecker et al., 2020, Cauvel, 2019), we also show that the relation between income inequality with output depends on the source of changes in the income distribution, giving rise to a policy dilemma when there is a trade-off between stimulating economic activity and productivity growth and promoting a more equal income distribution.

The remaining of this article is organized as follows. In section 2 the main features of the model are summarized. In section 3 the related literature is discussed. In section 4 the model structure is presented. Then, the baseline specification and the model's validation are discussed in section 5, while the experiment results are presented in section 6. Section 7 presents the sensitivity analysis, where we investigate the interaction between key model parameters. Concluding remarks follow in section 8.

2 Key features of the model

The model's basic structure is inspired by key contributions in the agent-based macroeconomic literature, such as the "Schumpeter meeting Keynes" model (Dosi et al., 2010, 2013, 2018), the micro-macro multisectoral model (Dweck, 2006, Dweck et al., 2020, Melo et al., 2016), as well as the models developed by Caiani et al. (2016, 2019a,b) and Oliveira et al. (2020). Its main contribution is to incorporate three aspects relevant to the recent changes in the functional and personal income distributions, which are particularly related to the neo-Kaleckian approach. More precisely, we intend to study the functional and personal income inequality dynamics in an economy intrinsically characterized by a complex and multifaceted class conflict over the distribution of income.

Firstly, we model a novel and fuller specified wage bargaining process in which the interaction between workers and firms is key to the wage determination. This approach, which has not yet been undertaken in the literature, intends to provide a broader and more detailed wage setting mechanism, rather than assuming that wages are unilaterally determined by one agent (firms or workers) and just accepted (or rejected) by the other agent. In our proposed model, workers can influence the nominal wage adjustment by firms through their bargaining power, which is assumed to reflect the institutional framework supporting workers and the macroeconomic context.

Secondly, firms' mark-up adjustment rule is assumed to depend on a strategic evaluation of their situation *vis-à-vis* their competitors and the working class, which is summarized by the evolution of their market shares and unit production costs respectively. This latter variable captures the interplay between productivity and nominal wage growth rates and signals to firms whether they may increase or maintain higher mark-up levels to take advantage of productivity growth, or they should keep their mark-ups at lower levels in order to prevent nominal wage increases from passing on entirely to prices and harming their competitiveness. As mark-ups are an expression of firms' power (the extent to which prices can be set above unit costs), this framework incorporates productivity growth as another facet of the class conflict over income distribution.

Finally, we link this class conflict dynamics and its effects on the functional income distribution to the personal income distribution through a class structure for households. We incorporate the sociological class division described by Mohun (2016), according to which capitalists receive non-labor income, the working class is characterized by being powerless in a specific sense (it is compelled to sell its labor power and is supervised by someone else), and the managerial class exercises supervisory functions, but, as the working class, does not have sufficient non-labor income. Accordingly, in our model households are split into three heterogeneous classes that perform different functions and earn different income levels.

3 Related literature

Our work relates to a growing agent-based modeling literature that deals with the relation between income distribution and productivity growth. For instance, Carvalho and Di Guilmi (2020) show how productivity growth can lead to changes in income distribution by considering labor-saving technological progress. In their model, productivity growth is associated with higher unemployment rates and leads to more inequality in the functional and personal income distributions. The relation between inequality and productivity growth is also analyzed in Ciarli et al. (2010), who deal with the relation between technological progress, firms' organizational structure and wages and earnings structure. In addition, Caiani et al. (2019b) deal with the link between productivity growth and inequality by focusing on how different distribution regimes affect the innovation dynamics. An alternative relation between productivity and inequality is explored by Caiani et al. (2019a), who assume an adaptive behavior of firms, which adjust prices depending on their sales and wages depending on whether they could fill all vacant job positions.[1]

An alternative analysis of the link between innovation and inequality is offered by models that focus on market concentration dynamics. These works draw on contributions documenting the increase in product market concentration associated with technological change and the existence of entry barriers. As the higher concentration benefits firms with higher mark-up rates, it is associated with the observed decreases in the wage share (Autor et al., 2020, De Loecker et al., 2020). In line with these works, Turco and Terranova (2021) explore how market concentration is affected by technical change and what are the implications for income inequality. The authors show that the dynamics can be markedly different depending on whether there are legal entry barriers (which affect concentration in the long run) and that economic policies can attenuate the tendency towards concentration or alter the macroeconomic results. Similarly, Dawid and Hepp (2021) capture the role of firms in shaping inequality dynamics in different technological regimes in a model where workers are heterogeneous with respect to their skills. They show that the effect of productivity growth on inequality strongly depends on how the type of technological regime changes and that the effect of market concentration on wage inequality can be ambiguous.

Inspired by these studies, this article contributes to the literature by linking the wage bargaining process based on firms' and workers' interaction to productivity growth. As this framework avoids the oversimplifications that lead to a superficial or absent interaction between firms and workers in the wage bargaining process that are commonly adopted in the literature, it allows for an endogenous determination of nominal wages. Combined with the new mark-up adjustment rule, this leads to an endogenous determination of the functional and personal income distribution.

[1] While productivity growth is also interpreted as an opportunity to increase profit margins in Caiani et al. (2019a), this results from an adaptive behavior of firms, rather than being determined strategically by firms following a mark-up pricing rule as proposed in our model.

4 The model

The model is composed of five types of agents:[2]

- A monopolist **capital goods firm**, which produces machines and undertakes research and development (R&D) activities.[3] It distributes to its owners all its net profits.
- A set of N^c **consumption goods firms**, which produce a homogeneous good using labor and machines. They invest in capital goods and may ask for a loan to finance production or investment.
- A monopolist **bank**, which grants loans to consumption goods firms, buys bonds from the government and holds firms' and households' deposits.
- A set of N^h **households** divided in N^{cap} capitalists, N^{dir} direct workers, and N^{ind} indirect workers. Workers sell their labor to firms and receive wages in return, while capitalists own the firms and receive profit dividends (each firm is owned by ρ_1 capitalist households). Unemployed workers receive a tax-exempt dole from the government. Households buy consumption goods and keep their savings as deposits at the bank. They also pay taxes on profit dividends and wages.
- A **public sector** composed by a central bank and a government. The government employs a fixed number of direct and indirect workers, pays unemployment benefits to unemployed workers, collects taxes, and issues bonds to cover its deficits. The central bank holds the government's reserves account and acquires government bonds.

The model structure and the interactions between the agents are represented in figure 1.[4]

4.1 Capital goods firm

The capital goods firm sector is represented by a monopolist firm, which produces a homogeneous capital good characterized by direct labor productivity $y_t^{c,\star}$. The firm uses direct labor as the sole production input and employs a production technique characterized by direct labor productivity y_t^k. The capital goods firm is responsible for the innovation process, which is the sole source of increases in the productivity of direct labor in the economy. In the beginning of each period, the firm receives

[2]The following subscripts are used throughout this article: h for households, c for consumption goods firms, m for machines, k for the capital goods firm, f for both firms, b for the bank, and g for the public sector. The superscripts res, man, ind, dir, and cap refer to researchers, managers, indirect workers, direct workers, and capitalists, respectively, while j refers to households from all classes. The superscripts \$, D, d , and e identify nominal, demand, desired, and expected variables, respectively. Finally, the subscript t identifies the time period, which encompasses the production, commercialization, and investment periods. Parameters that do not change in a given simulation are referred to as fixed parameters and, as such, are not accompanied by t.

[3]The assumption of monopolist agents is adopted in other models in the literature (Cardaci and Saraceno, 2018, Carvalho and Di Guilmi, 2020, Dweck et al., 2020, Oliveira et al., 2020) and is consistent with the idea of keeping the model as simple as possible in the elements that are less essential to the main relations under analysis.

[4]A detailed matrix presenting the transaction flows between the agents is reported in Appendix A. The model is implemented and simulated in the Laboratory for Simulation Development (LSD) software.

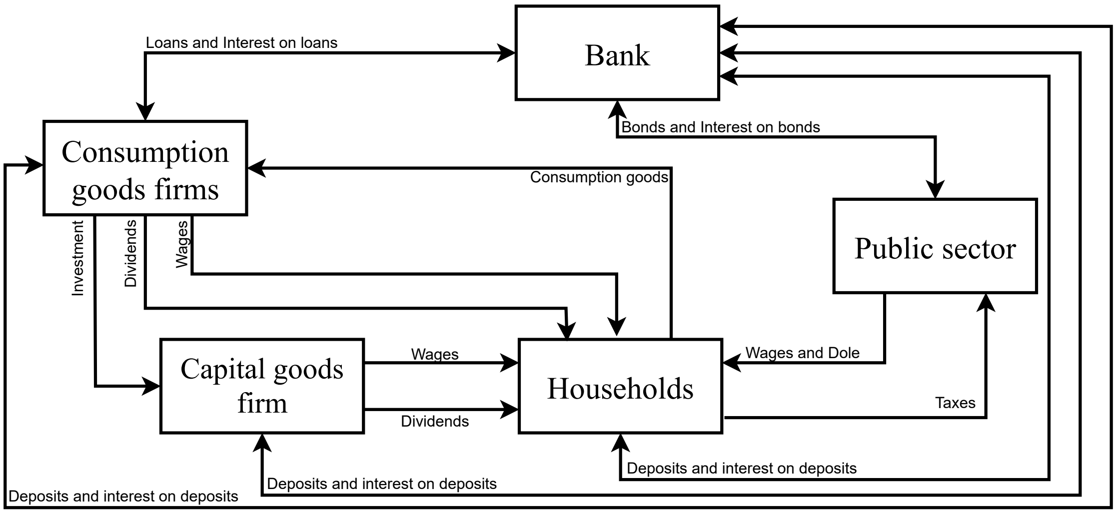


Figure 1: Model structure
Note: arrows point from paying sector to receiver sector.

orders of new machines from the consumption goods firms (aggregate investment demand), which are delivered in the end of the period.

4.1.1 Innovation

The capital goods firm invests a fixed fraction $\rho_2 < 1$ of the current period nominal investment demand on R&D and hires indirect workers to perform this activity. The innovation process depends on two successive random draws (Dosi et al., 2010, Nelson and Winter, 1982). Firstly, a Bernoulli draw determines whether the firm is successful in innovation, with the probability of success being a function of the number of researchers employed:

$$\theta_t = 1 - e^{-\zeta L^{res}_{k,t}} \tag{1}$$

where $0 < \zeta < 1$ is a parameter that reflects the firm's search capabilities.

If this first random draw is successful, the new technology is characterized by the pair $y_t^{c,in}$ and $y_t^{k,in}$:

$$y_t^{c,in} = y_t^{c,\star}(1 + x_t^c) \tag{2}$$

$$y_t^{k,in} = y_t^k(1 + x_t^k) \tag{3}$$

where x_t^c and x_t^k are random draws from a $Beta(\alpha, \beta)$ distribution over the $[-x, x]$ support.

A comparison with the previous technology determines whether the firm produces the new machines or stays with the previous one (Dosi et al., 2010), as it selects the technology that minimizes the sum of the price of the machine and the total production cost at the consumption goods firms' desired capacity utilization rate (u^d) times a payback factor:

$$min(p_k(y^k_{t-1}) + b\Gamma^{\$}(y^{c,\star}_{t-1}, u^d),\ p_k(y^{k,in}_{t-1}) + b\Gamma^{\$}(y^{c,in}_{t-1}, u^d)) \tag{4}$$

where p_k is the capital goods price function (see section 4.1.3), b is the exogenous payback factor, and $\Gamma^{\$}$ is the consumption goods firms' total cost function (see section 4.2.5).

4.1.2 Labor demand

The capital goods firm hires both direct and indirect workers. Direct workers are directly involved with the production process and are demanded in proportion to the consumption goods firms' investment demand in the period ($\sum_{c=1}^{N^c} I_{c,t}^D$), as follows:

$$L_{k,t}^{D,dir} = \left\lceil \frac{\sum_{c=1}^{N^c} I_{c,t}^D}{y_t^k} \right\rceil \tag{5}$$

Indirect workers are employed either as managers who supervise the production process or researchers. While the demand for the former depends on the demand for direct workers (equation 6), the demand for the latter is determined by the firm's R&D budget and the current wage level for indirect workers (equation 7):

$$L_{k,t}^{D,man} = \left\lfloor \rho_3 L_{k,t}^{D,dir} \right\rceil \tag{6}$$

$$L_{k,t}^{D,res} = \left\lfloor \frac{\rho_2 \sum_{c=1}^{N^c} I_{c,t}^D}{w_{k,t}^{ind,\$}} \right\rceil \tag{7}$$

where the parameter ρ_3 is the fixed number of managers per direct worker, $\rho_2 \sum_{c=1}^{N^c} I_{c,t}^D$ is the budget for R&D activities, and $w_{k,t}^{ind,\$}$ is the indirect workers' wage level. Since managers and researchers are indirect workers, the firm's total demand for indirect workers is $L_{k,t}^{D,ind} = L_{k,t}^{D,man} + L_{k,t}^{D,res}$.[5]

4.1.3 Pricing

The capital goods firm follows a cost-plus pricing rule:

$$p_{k,t}^{\$} = (1 + \mu_k) \frac{(w_{k,t}^{dir,\$} + \rho_3 w_{k,t}^{ind,\$})}{y_t^k} \tag{8}$$

where μ_k is a fixed mark-up rate and $w_{k,t}^{j,\$}$ is the wage rate for each type $j = dir, ind$ of worker.[6]

4.1.4 Production

The firm's production level is determined by the number of direct workers it hires in the period and their productivity ($\lfloor L_{k,t}^{dir} y_t^k \rfloor$). As the firm never produces more than demanded by the consumption goods firms (for simplicity, there is no strategic accumulation of inventories), $\sum_{c=1}^{N^c} I_{c,t}^D$ is the maximum production level of the capital goods firm.

[5]Hired indirect workers are split between researchers and managers proportionally to their participation in $L_{k,t}^{D,ind}$. Note that the demand for managers may be limited by the available resources in the period (considering the firm's deposits and expected revenue minus production costs).

[6]The use of mark-up rules is largely supported by the empirical literature based on surveys in different countries (Correa et al., 2018, Fabiani et al., 2006).

4.2 Consumption goods firms

The model is composed of a set of N^c consumption goods firms that produce a homogeneous nonperishable good using labor and capital goods. Demand expectations determine the desired production for the current period, while the realized production may be limited by financial constraints and labor availability. The expected production for the next period determines the desired investment level, which may also be limited by financial constraints upon firms. The firms' production of such homogeneous good is sold in the consumption goods market, where firms can nonetheless act as price makers in an imperfectly competitive market due to imperfect and incomplete knowledge on the part of consumers.

4.2.1 Expectations

Firms for their expectations based on their past experience in the labor market, in line with empirical evidence on adaptive expectation formation (Gennaioli et al., 2016, Boneva et al., 2020). This is formally represented as follows:

$$Q^{D,e,t}_{c,t} = \sum_{i=1}^{4} \omega_i Q^{D}_{c,t-i} \tag{9}$$

where $Q^{D}_{c,t-i}$ is the demand for the firms' products in $t-i$ and $\omega_1 > \omega_2 > \omega_3 > \omega_4 > 0$ are fixed parameters ($\sum_i^4 \omega_i = 1$). Expectations for demand in the following period ($Q^{D,e,t+1}_{c,t}$) are formed in a similar way and consider their expectations for the current period and demand from three previous periods.

4.2.2 Desired and expected production

Based on the expected sales and considering a fixed desired share of inventories (n^{IN}), firms form their desired production level for the current period (equation 10), which is limited by their production level at their full capacity utilization ($Q^{fc}_{c,t}$), and the expected production level for the next period (equation 11), as follows:

$$Q^{d}_{c,t} = min(Q^{fc}_{c,t}\ ,\ (1+n^{IN})Q^{D,e,t}_{c,t} - Q^{IN}_{c,t-1}) \tag{10}$$

$$Q^{e,t+1}_{c,t} = (1+n^{IN})Q^{D,e,t+1}_{c,t} - max(Q^{d}_{c,t} + Q^{IN}_{c,t-1} - Q^{D,e,t}_{c,t},\ 0) \tag{11}$$

where Q^{IN}_{t-1} is the previous period inventories.

4.2.3 Labor demand

The consumption goods firms also hire both types of workers. The demand for direct workers depends on their desired production and on the labor productivity, as follows:

$$L^{D,dir}_{c,t} = \left\lceil \frac{Q^{d}_{c,t}}{\bar{y}^{c,*}_{c,t}} \right\rceil \tag{12}$$

where $\bar{y}^{c,*}_{c,t}$ is the average direct labor productivity of the most productive machines required to produce $Q^d_{c,t}$.[7] Indirect workers are hired as managers to plan the firms' activities and supervise the direct workers' activities, so they are demanded proportionally to firms' size (proxied by the demand for direct workers at full capacity output level) and to the current demand for direct workers, as follows:

$$L^{D,ind}_{c,t} = \lfloor \rho_4 L^{D,dir}_{c,t} + \rho_5 L^{dir,fc}_{c,t} \rceil \tag{13}$$

where $\rho_{4,5} > 0$ are parameters and $L^{dir,fc}_{c,t}$ is the demand for direct labor at the full capacity production level. Firms hire as many workers as possible (given the labor supply constraints they face in the labor market) until their labor demand is met or all resources available are used.[8]

4.2.4 Production level

Firms' production is given by:

$$Q_{c,t} = L^{dir}_{c,t} \bar{y}^{c}_{c,t} \tag{14}$$

where $\bar{y}^c_{c,t}$ is the labor productivity of the most productive capital goods required to produce $Q_{c,t}$.

4.2.5 Pricing

The consumption goods firms follow the normal-cost pricing procedure (Lavoie, 2014, ch. 3). Accordingly, they add a variable mark-up rate over labor unit costs computed at the desired capacity utilization level. The mark-up rate has two components, with the first ($\mu^*_{c,t}$) capturing firms' position relative to other firms through the evolution of their market shares (Dosi et al., 2010, Dweck et al., 2020), as described in equation 15. The second component captures the evolution of their unit labor costs, which summarize the relation between productivity growth and nominal wages (firms' relation *vis-à-vis* workers). If these costs increase (decrease), it means that nominal wages increased more (less) than productivity, so this change is absorbed by firms through a negative (positive) adjustment in their mark-up deviation variable ($m_{c,t}$), as described by the adaptive mechanism in equation 16:

$$\mu^*_{c,t} = \mu^*_{c,t-1}\left(1 + \nu_1 \frac{\Delta ms_{c,t-1}}{ms_{c,t-2}}\right) \tag{15}$$

$$m_{c,t} = \nu_2 m_{c,t-1} - \nu_3 \left(\frac{\Delta \Gamma^{u,\$}_{c,t}(u^d)}{\Gamma^{u,\$}_{c,t-1}(u^d)}\right) \tag{16}$$

where $ms_{c,t-1}$ is the market share in the previous period, $\nu_1 > 0$ is the sensitivity of the mark-up to changes in market shares, $1 > \nu_2 > 0$ is the persistence in the mark-up deviation, $1 > \nu_3 > 0$ is the sensitivity of the mark-up deviation to changes in unit costs, and $\Gamma^{u,\$}_{c,t}(u^d)$ is firms' unit costs at desired capacity utilization rate. Prices are then given by $p^{\$}_{c,t} = (1 + \mu^*_{c,t} + m_{c,t})\Gamma^{u,\$}_{c,t}(u^d)$.

[7] In each period, the most productive machines are used first. When fully utilized, each machine can produce Q^{fc}_m consumption goods units.

[8] Available resources are split between direct and indirect workers following the same proportion as the relative labor demand for each type of worker.

4.2.6 Sales

Aggregate demand is split between firms according to their market share. As extensively assumed in the literature, firms' market shares evolve following a "quasi" replicator dynamics and depend on their competitiveness ($E_{c,t}$), which is given by the average between the normalized price level ($p^n_{c,t}$) and normalized unfilled demand level ($l^n_{c,t}$) (Dosi et al., 2010, Dweck et al., 2020, Silverberg et al., 1988). Formally, firms' competitiveness is given by equation 17 and their market share is given by equation 18, as follows:

$$E_{c,t} = \frac{(1 - p^n_{c,t}) + (1 - l^n_{c,t})}{2} \tag{17}$$

$$ms_{c,t} = ms_{c,t-1}\left(1 + \nu_4 \frac{E_{c,t} - \bar{E}_t}{\bar{E}_t}\right) \tag{18}$$

where $\nu_4 > 0$ is a parameter capturing the market share sensitivity to competitiveness and $\bar{E}_t$ is the average competitiveness of consumption goods firms weighted by firms' market shares in $t-1$.

4.2.7 Investment

Firms invest to adjust their capital stock to the desired level and to replace machines that have become technologically obsolete. In the first case, firms calculate their desired capital stock in $t+1$, which depends on the desired capacity utilization level ($Q^{fc,d}_{c,t} = Q^{e,t+1}_{c,t}/u^d$). The capacity adjustment investment is the difference between the desired production capacity for $t+1$ and the productive capacity in this period if no investment is undertaken (that is, if machines older than T^k periods are scrapped). In the second case, the replacement investment demand is determined by a payback rule (Dosi et al., 2010, Dweck et al., 2020). A machine is replaced by a new one if its payback period (equation 19) is positive and lower or equal to the fixed threshold b.[9]

$$b_{m,t} = \frac{p^\$_{k,t}}{\Gamma^\$(y^c_{m,t}, u^d) - \Gamma^\$(y^{c,\star}_t, u^d)} \tag{19}$$

Total investment demand is given by the sum of the capacity adjustment investment and the replacement investment, and it can be limited by the available resources in the period. The realized investment can be limited by the capital goods production (in case it could not hire all demanded direct workers in a given period).

4.2.8 Loans

Whenever their internal resources are insufficient to cover their expenses in the beginning of the period (before production and sales take place), firms asks for a loan from the bank. The bank grants all the requested loan as long as the ratio of firms' interest payment to their average revenue in the previous four periods (adjusted to the current price level) is below a maximum ratio, which is determined by the

[9] In case firms wish to reduce their productive capacity ($Q^{fc,d}_{c,t} < Q^{fc}_t$), replacement investment is reduced by the number of machines corresponding to the desired reduction.

exogenous parameter R. Otherwise, it grants the amount required to reach R or the amount required to cover firms' outstanding debt.[10]

4.2.9 Profits

Firms' gross and net profits are given by equations 20 and 21 respectively:

$$\Pi^{g,\$}_{c,t} = Q^{s}_{c,t}p^{\$}_{c,t} - (w^{dir,\$}_{c,t}L^{dir}_{c,t} + w^{ind,\$}_{c,t}L^{ind}_{c,t}) + \Delta Q^{IN}_{c,t}\Gamma^{u,\$}_{c,t} \tag{20}$$

$$\Pi^{n,\$}_{c,t} = \Pi^{g,\$}_{c,t} + Q^{IN}_{c,t-1}\Delta\Gamma^{u,\$}_{c,t} + i(D^{\$}_{c,t-1} - \Lambda^{\$}_{c,t-1}) \tag{21}$$

where $Q^{s}_{c,t}$ is the real sales, $\Gamma^{u,\$}_{c,t}$ is the unit production cost, i is the fixed interest rate, $D^{\$}_{c,t-1}$ is the firms' deposits in the previous period, and $\Lambda_{c,t-1}$ is the firms' total loans in the previous period.[11] At the end of each period, firms distribute their net profits to their owners.[12]

4.2.10 Exit and entry

Consumption goods firms exit the market whenever their market share is below a threshold given by the ms^{min} parameter. There is a one-to-one replacement of exited firms by new firms. The new firms' owners are selected among those whose firm exited the market in the period. They receive the deposits that their owners received when their previous firms exited the market (if any). The new firms enter the market by the end of the current period (t), invest in $t+1$ (investment demand given by a proportion δ of the average capital stock of the established firms), and start producing in $t+2$, when their market share is set equal to their full capacity production relative to the sector's total capacity production. After their first production period and for T^{c} periods thereafter, the firms receive all requested loan to finance their investment and production and are not subject to any exit criterion.

4.3 Bank

The banking sector is composed by a monopolist bank, which grants credit to firms, holds remunerated deposits and buys bonds from the government. For simplicity, the bank sets the interest rate for deposits and loans equal to the interest rate set by the central bank (i). As it is assumed that the bank is not owned by any household and that its activity involves no costs (it does not hire any workers), in case of positive (negative) profits, these are incorporated to (deduced from) its net worth.[13] Following the

[10] The latter condition simply means that firms pay back the entire sum of interest and principle even if the R ratio is reached. In other words, firms always have the possibility of rolling over their previous loans and loan defaults are a possibility only when firms exit the market.

[11] Inventories are evaluated at the current unit cost of production, in accordance with accounting rules, and the FIFO (first in, first out) criterion is adopted. This means that the change in the value of inventories is composed of the change in its volume (evaluated at the current unit cost of production) and of the change in the unit production cost (known as inventory appreciation). As only the former is related to a production flow, profits in national accounts are given by equation 20. See Godley and Lavoie (2012, ch. 8) for more details.

[12] The amount of profit dividends may be limited by the amount of resources available as deposits discounted by the resources necessary for loan repayment in the beginning of the next period (which are kept as deposits at the bank).

[13] For simplicity, we do not input a real value for the financial sector's services when computing real output. In order to guarantee consistency, we do not consider the bank's profits when calculating nominal output and the wage share. As the

post-Keynesian approach of endogenous money and credit rationing (Lavoie, 2014, Wolfson, 1996), we assume that credit is demand-led at a given interest rate conditional to a creditworthiness condition being fulfilled, as discussed in section 4.2.8.

4.4 Households

We follow Mohun's (2016) sociological class division and split households into three heterogeneous classes: direct workers, indirect workers (researchers and managers) and capitalists. Each household is composed of a single agent and the direct and indirect workers are employed in specific tiers of the firms. Capitalist households own the capital and consumption goods firms. For simplicity, there is no social mobility across classes and no population growth.

4.4.1 Worker's desired and reservation wages

Workers have both a desired wage and a reservation wage, which are affected by their individual experience in the labor market and by the macroeconomic context. Workers' desired wage depends on their previous positive wage adjusted by the accumulated inflation rate since their last employment period (if positive), as expressed by the inflation-adjusted wage ($w^{d,*,\$}_{h,t}$) in equation 22. In case workers have been employed in the previous period and the economy presented a positive growth rate, the adjusted wage is increased by a proportion of the previous period growth rate,[14] as shown in equation 23:

$$w^{d,*,\$}_{h,t} = max\left(w^{\$}_{h,t-1-T^w_{h,t}}\left(1+\gamma_1\frac{cpi_{t-1}-cpi_{t-2-T^w_{h,t}}}{cpi_{t-2-T^w_{h,t}}}\right),\ w^{\$}_{h,t-1-T^w_{h,t}}\right) \tag{22}$$

$$w^{d,\$}_{h,t} = \begin{cases} w^{d,*,\$}_{h,t}(1+\gamma_2 g_{t-1}) & \text{if } T^w_{h,t}=0 \text{ and } g_{t-1}>0, \\ w^{d,*,\$}_{h,t} & \text{otherwise.} \end{cases} \tag{23}$$

where $w^{\$}_{h,t-1-T^w_{h,t}}$ is the last strictly positive wage received by the worker, cpi_t is the consumer price index, $T^w_{h,t}$ is the number of periods the worker has been unemployed since her last employment (if employed in $t-1$, $T^w_{h,t}=0$), g_{t-1} is the previous period private aggregate demand growth rate, and $\gamma_{1,2}>0$ are parameters that capture the sensitivity to the inflation and growth rates respectively.[15]

Workers' reservation wage, which establishes the minimum wage they accept when looking for a job, depends on their individual experience in the labor market and decreases with the number of periods they have been unemployed, as follows in equation 24. The intuition is that workers become more likely to accept a lower wage if they have been unemployed for a longer interval, in line with the idea that unemployment experiences tend to lead to a lower wage (Blanchflower, 1991). There is also

interest rate on bonds, loans, and deposits is the same, the bank's profits are almost negligible. This is also the reason why it is assumed that the bank has no owners.

[14] More specifically, workers consider the growth rate of private aggregate demand, since they are bargaining wages with the consumption and capital goods firms.

[15] Workers' desired wage will always be at least equal to the minimum wage set by the government.

a minimum difference between the desired and reservation wage regardless of workers' employment status, so workers always accept a wage that is slightly below their desired wage.

$$w_{h,t}^{r,\$} = w_{h,t}^{d,\$}(1 - \gamma_3 T_{h,t}^{w} - \gamma_4) \tag{24}$$

where $\gamma_{3,4} > 0$ are fixed parameters capturing the sensitivity of workers' reservation wage to the number of unemployment periods and the minimum difference between the desired and reservation wages respectively.[16]

4.4.2 Households' consumption

Similarly to Caiani et al. (2019b), our approach to households' consumption follows Duesenberry's (1949) relative income theory. We assume that there are class-specific propensities to consume (Dynan et al., 2004), since lower income groups tend to consume a larger fraction of their income. There are different reasons for this, such as relative consumption comparisons ("keeping up with the Joneses" effect) or rich households' attitude towards savings as an end to itself and source of power and status (Carroll, 2000).[17] There is also a partial downward rigidity in households' real consumption level. Formally, nominal consumption demand is determined as follows:

$$C_{h,t}^{D,\$} = max\left(c_1 \frac{C_{h,t-1}^{D,\$}}{\bar{p}_{c,t-1}} \bar{p}_{c,t}^{*},\ c_2^{j}((w_{h,t}^{\$} + \Pi_{h,t-1}^{h,\$})(1-\tau) + d_{h,t}^{\$})\right) \tag{25}$$

where $1 > c_1 > 0$ is the real consumption persistence, $\bar{p}_{c,t}^{*}$ is the weighted average price in t (considering firms' market shares in $t-1$), $\bar{p}_{c,t-1}$ is the weighted average price in the previous period, $1 > c_2^{j} > 0$ is the propensity to consume out of income for each class $j = dir, ind, cap$, $w_{h,t}^{\$}$ is the wage earned by the household, $\Pi_{h,t-1}^{h,\$}$ is the profit dividends from the previous period, $d_{h,t}^{\$}$ is the tax-exempt unemployment dole received by unemployed workers and τ is the tax rate on income. As households do not have access to the credit market, $C_{h,t}^{D,\$}$ may be limited by their available financial resources (deposits).

4.5 Public sector

The public sector is composed of a government and a central bank. The government collects taxes on households' income at a tax rate τ. It pays unemployment benefits to unemployed workers at a value equal to the minimum wage ($w_t^{min,\$}$), which is is adjusted by the average wage inflation rate in the previous period.[18] The public sector also hires a fixed number of direct and indirect workers as public

[16] Once again, the reservation wage is never lower than the minimum wage.

[17] This is also related to the interplay between household debt, inequality and consumption (Cynamon and Fazzari, 2008, Kim et al., 2014, 2015). As we assume that households have no access to the credit market, this relation is out of our scope. For agent-based models that deal with the relation between inequality and household debt, see Cardaci and Saraceno (2018) and Carvalho and Di Guilmi (2020).

[18] This adjustment rule represents a neutral minimum wage policy that does not target a specific redistributive outcome.

servants (L_g^{dir} and L_g^{ind}), who are paid the average wage paid for their class in the consumption goods sector.[19] For simplicity, it is assumed that these workers are not subject to any turnover.[20]

The government maintains a current account at the central bank and the latter holds government bonds in its balance sheet. Therefore, in each period, when the government spends, it issues new government bonds that are acquired by the central bank (unless the government's deposits at the central bank are enough to cover the total expenditure). The central bank then transfers the required amount of reserves to the bank, which credits the firms' or households' current accounts accordingly. When taxes are paid, the opposite occurs: the bank transfers reserves to the central bank and the government's account at the central bank is credited. At the end of the period, in line with the reflux principle emphasized in the post-Keynesian literature (Lavoie, 2014, ch. 4), if the government runs a deficit, the bank ends up with reserves that don't earn any interest and thus acquires government bonds from the central bank.

4.6 Labor market

We assume that both our indirect and direct workers belong to the primary sector of the labor market, insofar as they are either managers or factory workers whose employment is long-term and full-time (Bewley, 2007).[21] Accordingly, firms follow an internal pay structure that determines the entry wage of newly hired employees, with workers at the same firm and the same category earning the same wage. Following the evidence on nominal downward wage rigidity, we assume that firms do not cut nominal wages (Bewley, 2007, Dickens et al., 2007).[22] Finally, workers are fired if firms' demand for workers is lower than the current number of employees (i.e., there is no labor hoarding) or to meet the employees turnover target (given by the ϑ parameter).[23] Workers, on the other hand, look for new opportunities in the labor market if they have been fired or if their current employer offered them a wage lower than their reservation wage.

4.6.1 Wage setting

The wage setting process is organized into a few steps. Firstly, firms decide their desired wage ($w_{f,t}^{j,d,\$}$, where $j = dir,\ ind$), which, for simplicity, is equal to the wage level paid in the previous period ($w_{f,t-1}^{j,\$}$). Then, in line with the idea that labor market surveys of pay rates for positions that are common to many firms can be used when firms adjust their wage levels (Bewley, 2007), they consult a

[19] Government expenditure in real terms is calculated assuming that the productivity of direct workers in the public sector grows in line with the average productivity in the private sector.

[20] In other words, the government never lays off its employees and the public servants never quit their job. This simplifying assumption is adopted in order to reduce the influence of the government's demand for labor in the labor market.

[21] However important, our model does not intend to explore the effect of labor market reforms that have facilitated flexibility and created the so-called dual labor market, wherein primary sector workers are relatively more insulated from labor market fluctuations than secondary sector workers (Caju et al., 2015). In this sense, we aim to capture a more collective dimension of workers' bargaining power, rather than individual dimensions that nonetheless may have macro implications. For a complementary discussion on labor market flexibility in an agent-based framework, see Dosi et al. (2017, 2018).

[22] This also means that negative inflation rates are not considered when workers adjust their desired wages or in the minimum wage adjustment.

[23] The firm may also have to fire additional workers in case it does not have the financial resources to hire them in the current period. Workers to be fired are randomly selected among current employees.

random set of workers in the private sector in order to assess their average desired wage level ($w_{f,t}^{j,s,\$}$). For simplicity, we assume that this survey is costless. The number of workers surveyed is a proportion $n^{s,j}$ of firms' demand for workers from class $j = dir,\ ind$. The fact that each firm surveys a different sample reflects their limited and localized knowledge, so the survey can be interpreted as a metaphor to this limited knowledge in firms' assessment of the labor market conditions. Finally, the wage offered ($w_{f,t}^{j,\$}$) is a weighted average between firms' desired wage ($w_{f,t}^{j,d,\$}$) and the surveyed wage ($w_{f,t}^{j,s,\$}$).We assume that firms take into consideration the employment rate (η_{t-1}) when setting the weight given to the wage survey, as a higher employment rate increases workers' bargaining power. These relations are described by equation 26 below:

$$w_{f,t}^{j,\$} = (1 - \phi\eta_t)w_{f,t}^{j,d,\$} + \phi\eta_t w_{f,t}^{j,s,\$} \tag{26}$$

where $0 < \phi < 1$ is a fixed parameter capturing the sensitivity of workers' bargaining power to the employment rate. Thus, workers' bargaining power is given by $\phi\eta_t$, which captures how close the average nominal wage is to the average wage desired by workers.[24]

4.6.2 Hiring process

Once the number of open job posts for each type of worker is defined, the firms interact with workers in the labor market. This interaction is modeled as a random process in order to mimic the complex and diverse nature of the job offer and search processes in reality, similarly to the process put forward by Riccetti et al. (2015). A random list of firms is formed with the capital goods firm always being in the first position. The first firm tries to match with an indirect and a direct worker by randomly selecting a worker of each type. Workers accept an offer if the offered wage is above their reservation wage; otherwise, the hiring round will have been unsuccessful. After this, the second firm starts its hiring round and so on until all firms in the list have executed one hiring round for each type of worker. The process iterates until all firms have filled all open positions or reached the maximum number of hiring rounds for each type of worker, given by a multiple n^w of the number of open positions.

4.7 Sequence of events

In each simulation period, the sequence of events is the following:

1. Interest on deposits and on government bonds are paid;
2. Consumption goods firms set desired production levels;
3. Wages are set;

[24] Fagiolo et al. (2004) adopt a similar equation, but in their model firms' bargaining power is exogenous. Our model captures two important determinants of workers' bargaining power dynamics: institutions that support workers' bargaining power (captured by the ϕ parameter) and changes in the employment rate. This allows for a richer and more encompassing analysis of income distribution dynamics, as the same wage share can result from different combinations of ϕ and η_t and, consequently, can be related to markedly different macroeconomic contexts, as discussed by Setterfield (2021). The inclusion of productivity growth adds a third determinant to the story, as shown in our results in section 6.

4. Capital goods firm sets the price and technology used and embodied in new machines;
5. Credit market opens;
6. Consumption goods firms set investment demand;
7. Labor market opens;
8. Production and R&D activities take place;
9. Unemployment doles and wages are paid;
10. Consumption goods market opens;
11. Taxes are paid;
12. Bank acquires government bonds from the central bank;
13. New machines are delivered and old machines are scrapped;
14. National accounts and statistics are computed;
15. Exit and entry of consumption goods firms take place.

5 Model validation

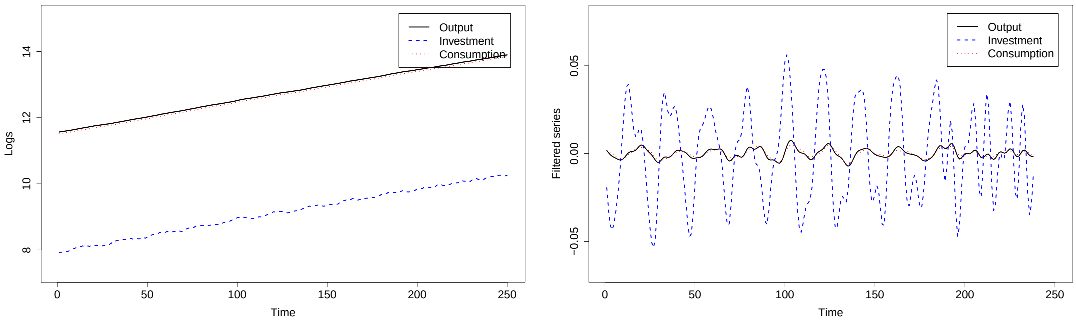
The model is simulated for 500 periods (250 transient periods and 250 considered periods).[25] This section reports the main average results for the 100 Monte Carlo simulations for the baseline scenario, whose parameters and initial values are reported in Appendix B. We initially analyze the model's ability to reproduce important stylized facts identified in the empirical literature, with special attention being given to stylized facts related to the income distribution dynamics. Before proceeding further, it should be noted that while we did rely on parameters reported in empirical studies as much as possible, we did not estimate the model based on actual data. Accordingly, our calibration procedure mainly intended to obtain plausible results in the baseline scenario that do not deviate from qualitative and stylized properties that are observed in the actual data. This analytical approach provides a sound basis to interpreting our experiment results as reflecting plausible theoretical relationships and causal mechanisms.

5.1 Micro and macro

We start the empirical validation of the qualitative properties of the model by exploring its macroeconomic properties. Figure 2 shows that the main macroeconomic variables (output, consumption, and investment) present a sustained growth pattern with fluctuations. In addition, investment is more volatile than output and consumption is less volatile than output (Carlin and Soskice, 2014): the

[25] Unless mentioned otherwise, all figures, tables, and statistics refer to the time span from period 251 to 500.

standard deviation of consumption relative to output is equal to 0.814, while the standard deviation of investment relative to output is equal to 8.509.

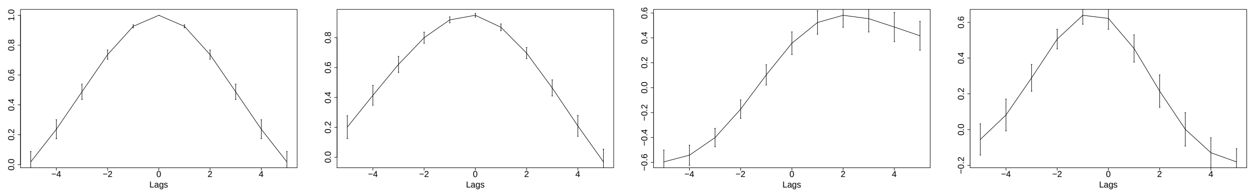


(a) Level (logs) (b) Cycle (Bpf)

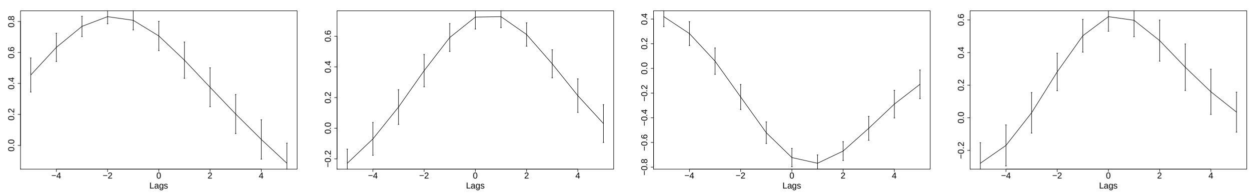
Figure 2: Output, consumption, and investment

Note: Bpf: bandpass-filtered (6,32,12). All series are taken in logarithm.

Figure 3 shows the cross-correlations between the cyclical components of output and selected macroeconomic series obtained through the bandpass filter. As reported by Carlin and Soskice (2014) and Stock and Watson (1999), we observe that consumption is procyclical and coincident with output and investment is procyclical, but leading output.[26] Also in line with the empirical evidence, we observe that the change in inventories is procyclical, average labor productivity is procyclical, and capacity utilization is procyclical. We find that the unemployment rate is countercyclical, reflecting the positive effect of higher output levels on employment (despite of the increase in productivity). In addition, we find that the cyclical component of the inflation rate is procyclical.



(a) Output (b) Consumption (c) Investment (d) Inventories change



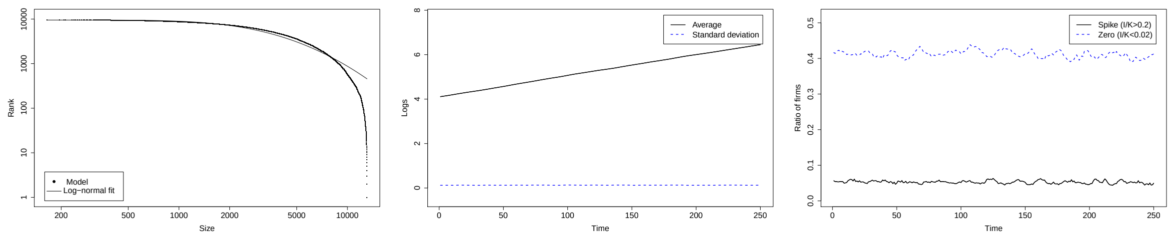
(e) Labor productivity (f) Capacity utilization (g) Unemployment rate (h) Inflation rate

Figure 3: Cross-correlations structure for output

Note: Bpf: bandpass-filtered (6,32,12). Output, consumption, investment, change in inventories, and average productivity series are taken in logarithm. Bars are standard deviations of 100 Monte Carlo average cross-correlations.

[26] Stock and Watson (1999) show that investment tends to be coincident with output. In our model, a leading investment probably results from the effect of replacement investment and to productivity growth being the main driver of growth.

The model also reproduces microeconomic characteristics, reflecting the heterogeneity of the consumption goods firms that emerges during the simulations.[27] The Zipf plot in figure 4a suggests that firms are very heterogeneous with respect to their sizes (measured by their real sales) and that the log-normal fits the data well except for the upper tail (Stanley et al., 1995). The deviation from log normality is confirmed by the Jarque-Bera normality test, which presents a p-value of 0 (test statistics is 605.932). There is also evidence indicating that the distribution of firms growth rates (measured by sales growth) presents tails fatter than a Gaussian distribution (Bottazzi and Secchi, 2003), since the fitted exponential-power distribution presents a shape parameter equal to 1.367 (standard deviation equal to 0.078). In exponential-power distributions, when the shape parameter is below two (which reflects a Gaussian distribution), events at the extreme of the distribution (very high or very low growth rates) are more frequent than it would be expected in case of normally distributed shocks.



(a) Sales distribution (pooled) (b) Productivity in C sector (c) Investment lumpiness

Figure 4: Stylized microeconomic facts (consumption goods sector)

Note: Period for figure 4a: 500.

We find that there is a significant productivity differential across firms (Barth et al., 2016, Dosi, 2007, Dunne et al., 2004), as reflected in the standard deviation reported in figure 4b. There is also evidence of strong autocorrelation in firms' productivity levels, as the average autocorrelation of productivity is 0.968 for the first lag (standard deviation equal to 0.009) and 0.951 for the second lag (standard deviation equal to 0.013). This indicates that differences in productivity tend to be persistent, as suggested by Dosi (2007). Finally, as reported in figure 4c, we observe that investment is lumpy (Doms and Dunne, 1998), with some firms experiencing investment spikes simultaneously to other firms presenting very low or no investment at all.

5.2 Wages and income distribution

As reported in table 1, the wage share and the Gini coefficient of income are countercyclical and the real wage is procyclical.[28] While the countercyclicality of the wage share indicates that labor productivity is more responsive to the cycle than the real wage (Giovannoni, 2010), the countercyclicality in the income Gini coefficient reflects the disproportional effect of lower output and higher unemployment on people at the bottom of the income distribution, who then earn an even lower income when unemployed (e.g. unemployment dole), leading to increases in income inequality (Maestri and Roventini, 2012, Hoover et al., 2009). This positive relation between unemployment and the income Gini coefficient

[27] Note that the same initial conditions are used for all firms in the consumption goods sector.

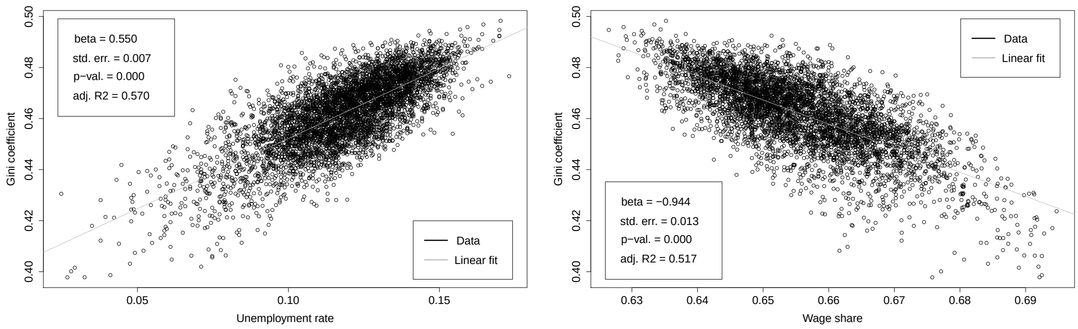
[28] For a discussion on the cyclical behavior of the real wage, see Bils (1985) and Solon et al. (1994).

is also shown in figure 5a. Thus, at the peak of the business cycle, the lower unemployment rate counterbalances the inequality-inducing effect of a lower wage share, which is reproduced in figure 5b. This negative relation between the wage share and the income Gini coefficient is due to relative (more income to lower classes) and composition (more income directed to a class whose income is more equally distributed than capital income) effects of a higher wage share (Daudey and García-Peñalosa, 2007, Wolff and Zacharias, 2013).

Table 1: Contemporaneous correlation with output (Bpf)

	Correlation	Standard deviation	p-value
Income Gini (Bpf)	-0.019	0.136	0.001
Wage share (Bpf)	-0.511	0.103	0.000
Real wages (Bpf)	0.570	0.107	0.000

Note: Bpf: bandpass-filtered (6,32,12). Output and real wage series taken in logarithm.



(a) Unemployment and Gini coefficient

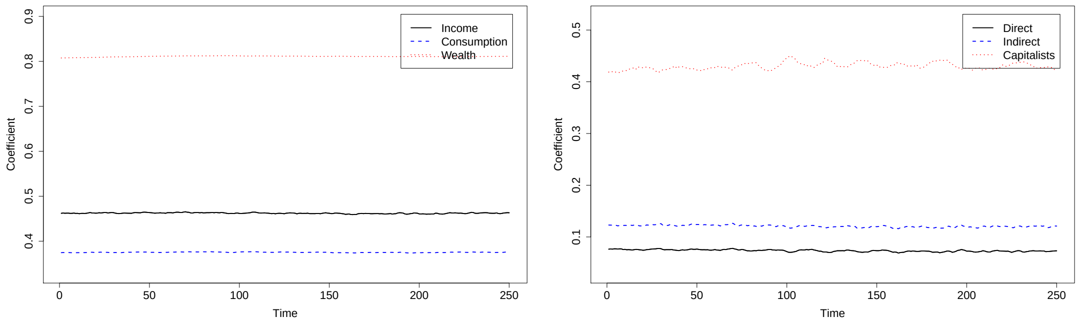
(b) Wage share and Gini coefficient

Figure 5: Scatter plots

Note: Periods: 451 to 500. The number of periods has been adjusted to allow a better visualization.

Figure 6a shows that the model also reproduces empirical observations concerning different inequality measures. We find that income inequality is larger than consumption inequality (Maestri and Roventini, 2012, Fisher et al., 2013, Heathcote et al., 2010) and wealth inequality is larger than income inequality (Brzozowski et al., 2010).[29] Also, the pattern of within-class inequality reported in Figure 6b is markedly different across income groups and reproduces the main aspects identified by Wolff and Zacharias (2013), who find that the intra-class income Gini coefficient is higher for capitalists than for employees and that the intra-class income Gini coefficient for classes with a lower mean income tends to be lower than for classes with higher mean income.

[29] In the model, wealth inequality refers to the distribution of deposits held by the households as this is the only asset held by households whose value is measured.



(a) Income, consumption, and wealth
(b) Within-class inequality

Figure 6: Gini coefficients

6 Class conflict: productivity, mark-up rates and wages

The literature on the recent income inequality dynamics indicates the importance of productivity growth and the lowering of workers' bargaining power. This interplay is key in our model and leads to an endogenous determination of the income distribution. Productivity growth allows firms to increase their mark-up rates as they face lower unit labor costs and thus represents an increase in their relative power *vis-à-vis* workers. Counteracting those forces, workers' bargaining power affects the evolution of nominal wages. The functional income distribution and real wages are the final result from the interaction between firms' strength (expressed primarily in prices) and workers' strength (expressed primarily in nominal wages) and, through our class structure, entail implications for the personal income distribution.[30]

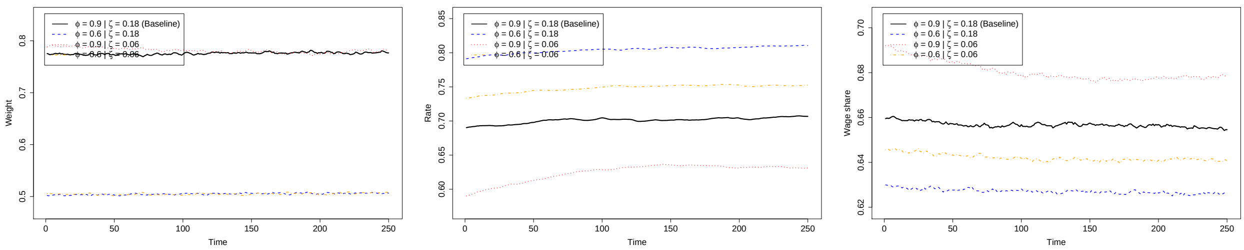
In order to further explore these relations, we investigate how these aspects operate individually and jointly by analyzing the effect of the sensitivity of workers' strength in the bargaining process to changes in the employment rate (ϕ), which is expected to lead to different levels of workers' bargaining power (equation 26), and the effect of changes in the capital good firm's access to innovation (the ζ parameter in equation 1, which we refer to as the innovation easiness parameter). The experiment settings define an economic structure favorable for workers ($\phi = 0.9$ and $\zeta = 0.06$), favorable for firms ($\phi = 0.6$ and $\zeta = 0.18$), and two intermediate cases which affect firms and workers in different directions ($\phi = 0.9$ and $\zeta = 0.18$, which is our baseline scenario, and $\phi = 0.6$ and $\zeta = 0.06$).

We observe that workers' bargaining power varies with the values of the ϕ and ζ parameters, thus altering the functional income distribution (figure 7).[31] The scenarios that present the lowest mark-up rates and, consequently, highest wage shares are the ones with the highest ϕ parameter, regardless of the value of the ζ parameter. This indicates that, at least for the parameter values adopted here, the effect of workers' bargaining power on the income distribution has a stronger effect on the income distribution than the productivity dynamics. Nevertheless, the productivity dynamics is also key for the results: despite of an almost negligible difference in workers' bargaining power associated with

[30] Note that there is an intrinsic asymmetry in the class conflict: firms strength will be manifested both in the labor market when they negotiate with workers and in their pricing decisions, while workers' strength only affects nominal wages.
[31] Average values for the main variables are reported in Appendix C.

the different values of ζ when ϕ is kept constant, there is a significant difference between the wage share in each scenario. This reveals the dual effect exerted by productivity growth in the model: it directly reduces unit labor costs if nominal wages are constant, but, by increasing unemployment rates (as shown below), it also reduces workers' bargaining power in the wage bargaining and increases the number of workers that do not increase their desired real wage due to being unemployed, thus affecting the average nominal wage dynamics.

The most favorable scenario for firms ($\phi = 0.6$ and $\zeta = 0.18$) is the scenario with the highest mark-up rate and lowest wage share. Indeed, in this case firms benefit from lower cost pressures, as nominal wage adjustments are lower, and they can take advantage of the high productivity growth to increase their mark-ups. The opposite occurs in the scenario that is most favorable for workers ($\phi = 0.9$ and $\zeta = 0.06$), as nominal wage adjustments will follow more closely the desired values by workers and productivity growth will be lower, reducing firms' opportunities to increase their mark-ups. As expected, our intermediate cases present intermediate values for the wage share and mark-ups. In the scenario with low workers' bargaining power and low innovation easiness ($\phi = 0.6$ and $\zeta = 0.06$), nominal wage adjustments exert a weaker downward pressure on mark-ups, but firms also have lower leeway to increase their mark-ups due to the lower productivity growth. Conversely, in the scenario with high workers' bargaining power and high innovation easiness (our baseline specification with $\phi = 0.9$ and $\zeta = 0.18$), nominal wage adjustments present a stronger downward pressure on mark-ups, but the higher productivity growth strengthens firms and they can (at least partially) sustain their mark-up rates.

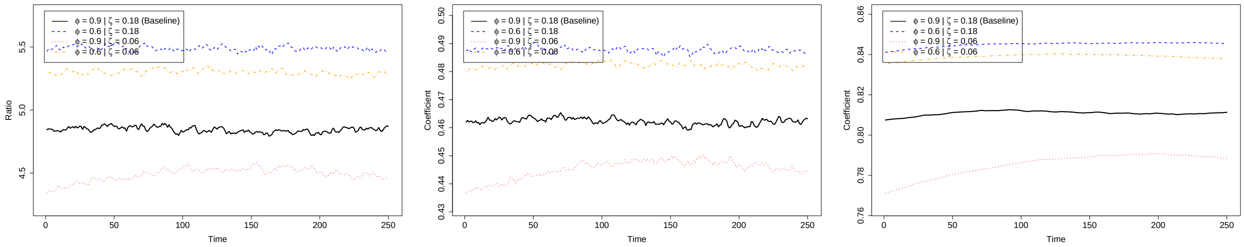


(a) Workers' bargaining power (b) Average mark-ups (C sector) (c) Wage share

Figure 7: Experiments comparison: wage bargaining and functional income distribution (alternative values of ϕ and ζ)

Note: Higher values of ϕ represent a higher sensitivity of workers' bargaining power to changes in the employment rate and higher values of ζ represent more innovation easiness.

As reported in figure 8, the different patterns in the functional income distribution lead to important differences in the personal income and wealth distributions. Indeed, we find that a higher wage share is always associated with a more equal distribution of income and wealth, so the most favorable scenario for workers ($\phi = 0.9$ and $\zeta = 0.06$) presents the lowest inequality indicators and the most favorable scenario for firms ($\phi = 0.6$ and $\zeta = 0.18$) leads to the highest inequality indicators among the different scenarios.



(a) Profit dividends to wages (b) Income Gini coefficient (c) Wealth Gini coefficient

Figure 8: Experiments comparison: personal income and wealth inequality (alternative values of ϕ and ζ)

Note: Higher values of ϕ represent a higher sensitivity of workers' bargaining power to changes in the employment rate and higher values of ζ represent more innovation easiness.

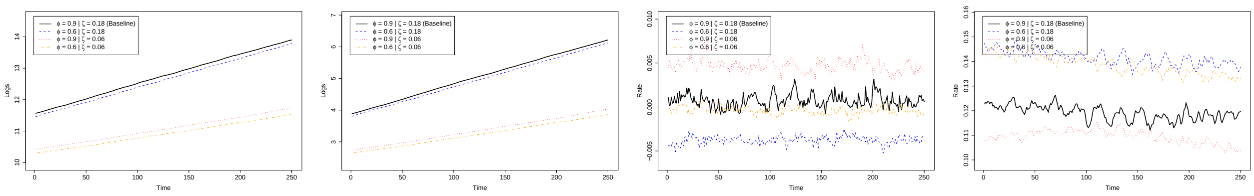
The macroeconomic implications of the different scenarios are reported in figure 9. We observe that increases in either ζ or ϕ, while keeping the other parameter constant, lead to increases in output. Since a higher ζ is associated with more inequality and a higher ϕ is associated with less inequality, this suggests that a higher wage share and lower personal income inequality can present different relations with output and productivity depending on the type of shock.[32] More importantly, regardless of the level of the ζ parameter, economic activity can be further stimulated and more equality can be achieved if workers' bargaining power is strengthened (higher ϕ parameter). When we compare the unemployment rate for each level of the ϕ parameter, we observe a lower unemployment rate when ζ decreases, despite of the lower output level, due to the technological unemployment effect that arises in this case. Yet, when ζ is kept fixed, a higher ϕ parameter is always associated with lower unemployment rate and higher output and productivity rates. Therefore, also the unemployment rate will present different relations with the output level depending on the type of shock, suggesting that whether a higher output level translates into lower unemployment or not crucially depends on productivity gains being shared with workers.[33] This indicates that productivity growth may be insufficient to promote better living conditions for the society as a whole, since the economic improvement obtained through a higher ζ parameter is concentrated in the wealthier households, while the working class will collectively face a reduction in the wage share and an increase in the number of workers unemployed. Finally, we also observe that higher unemployment rates are associated with lower inflation rates, in line with the conflicting-claims inflation model (Rowthorn, 1977, Summa and Braga, 2019).[34] While this suggests that there is an "inflationary cost" in order to keep the unemployment rate at low levels, an alternative

[32] This is an important insight for empirical studies investigating the relation between income distribution and economic activity, as these studies may capture a negative correlation between the wage share and output that is mostly due to the productivity dynamics and, consequently, has limitations as a counterfactual (how the economy would behave in case workers' bargaining power was enhanced by institutional changes) or as an explanation to the performance of an economy during a specific period (e.g., what was the contribution of specific policies aiming to increase the nominal wage). Given this endogeneity of the wage share, an alternative strategy for empirical studies would be to use the components of the wage share. This is the case of Cauvel (2019), who replaces the wage share with the real wage rate and labor productivity.

[33] Note that even when workers' bargaining power is high ($\phi = 0.9$), productivity gains are not entirely shared with workers, since this depends on the parameters associated with the mark-up deviation (equation 16). If productivity growth is higher, firms will still be able to maintain relatively higher mark-up rates, even if partially limited by the higher workers' bargaining power. This explains why for each level of ϕ the unemployment rate is higher in the scenarios with higher ζ (which are associated with more productivity growth).

[34] See Santoro (2020, ch. 2) for an agent-based model also inspired by the conflicting-claims inflation model.

interpretation is also possible: in order to keep inflation at low levels (either through lower workers' bargaining power or productivity growth), there is an "unemployment and inequality cost" (which is not necessarily associated with an "output cost").



(a) Output level (b) Average productivity (c) Inflation rate (d) Unemployment rate

Figure 9: Experiments comparison: macroeconomic series (alternative values of ϕ and ζ)
Note: Higher values of ϕ represent a higher sensitivity of workers' bargaining power to changes in the employment rate and higher values of ζ represent more innovation easiness.

7 Sensitivity analysis

In order to further explore our model's behavior, we perform a global sensitivity analysis exploring joint variations of 11 parameters that are key for the dynamics of output and productivity growth and workers' bargaining power. The methodology for the sensitivity analysis follows the work by Salle and Yıldızoğlu (2014). We employ the Nearly Orthogonal Latin Hypercube (NOLH) sampling as a design of experiment method. This method selects in a parsimonious way a sample of the possible parameters combinations in the entire parameters domain. The data collected from the 33 design of experiment samples and ten external samples is used to construct the Sobol decomposition and estimate a Kriging meta-model, which relate the parameters and the variables of interest.

We firstly analyze the Sobol decomposition for all the parameters analyzed in the sensitivity analysis (table 2). This analysis decomposes the variance of the selected computational output (simulation result) in contributions from each input parameter.[35] As expected due to the key role of productivity growth on output growth, we find that the main parameters affecting the growth rate dynamics are those related to innovation dynamics (x and ζ) and firms' replacement investment (b). Interestingly, the sensitivity analysis does not capture a direct effect of the sensitivity of workers' bargaining power to the employment rate (ϕ) on the growth rate. This is likely because its effect is mediated by the difference between the propensity to consume out of income between the different classes, which are also included in the sensitivity analysis. We also find that parameters related to the firms' mark-up setting rule (ν_3), the innovation dynamics (ζ), and workers' bargaining power (ϕ) exert an important effect on the wage share. As for the personal income distribution, it is also significantly affected by the parameters related firms' mark-up setting rule (ν_3) and the innovation dynamics (ζ). The propensity to consume out of income for capitalists (c_2^{cap}) also exerts a large effect on the Gini coefficient. Overall, these relations are in line with our conjecture that it is the interaction between workers' bargaining power and productivity growth that mostly determines the personal and functional income distributions.

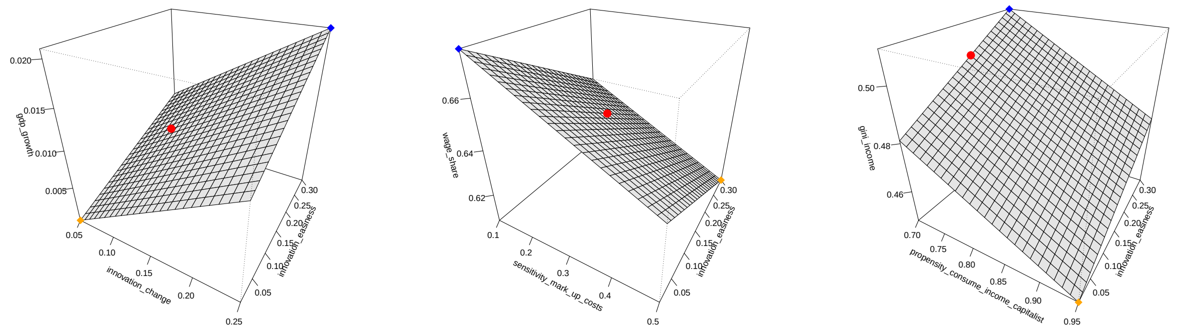
[35]See Sobol (2001) for more details.

Table 2: Sobol decomposition: direct effects and interactions

Param.	Description	Param. Range	Output growth		Wage share		Income Gini coef.	
			Dir.	Inter.	Dir.	Inter.	Dir.	Inter.
γ_1	sensitivity of desired wage by workers to inflation (eq. 22)	[0.5, 1]	0.001	0.001	0	0.001	0	0.001
γ_2	sensitivity of desired wage by workers to output growth rate (eq. 23)	[0.5, 1]	0	0.001	0.047	0.001	0.004	0.001
ν_3	sensitivity of mark-up rate to unit costs (C firms) (eq. 16)	[0.1, 0.5]	0.004	0.001	0.27⋆	0.001	0.137⋆	0.002
ϕ	sensitivity of surveyed wage weight in bargaining to employment rate (eq. 26)	[0.3, 0.9]	0	0.001	0.21⋆	0.001	0.012	0.001
ρ_2	proportion of revenue to R&D (K firms) (eq. 7)	[0.1, 0.3]	0.062	0.002	0.001	0.001	0.009	0.001
ζ	search capability (K firm) (eq. 1)	[0.01, 0.3]	0.255⋆	0.002	0.224⋆	0.001	0.27⋆	0.002
b	payback rule threshold (eq. 4)	[0.5, 3]	0.111⋆	0.002	0.005	0.001	0.058	0.001
c_2^{dir}	propensity to consume out of income (direct workers) (eq. 25)	[0.7, 0.95]	0.003	0.002	0	0.001	0.009	0.001
c_2^{ind}	propensity to consume out of income (indirect workers) (eq. 25)	[0.7, 0.95]	0.004	0.002	0.025	0.001	0.035	0.001
c_2^{cap}	propensity to consume out of income (capitalists) (eq. 25)	[0.7, 0.95]	0.002	0.002	0	0.001	0.363⋆	0.001
x	Beta distribution support (innovation) (eq. 2)	[0.05, 0.25]	0.555⋆	0.001	0.205	0.001	0.099	0.001

Note: ⋆ denotes the three most important inputs for each output. Equation numbers in parentheses indicate the equation in which the parameters first appears.

Figure 10 shows the response surfaces modeled by the Kriging meta-model for the two most important parameters identified by the Sobol decomposition for each model output (which is always in the vertical axis). Figure 10a indicates that when the capital goods firm has more access to innovation (ζ) or when higher productivity gains from innovation are possible (x), output growth rates are higher. These parameters allow for more productivity growth, which is a key driver of output growth in the model. Figure 10b indicates a negative effect of the ζ parameter on the wage share, which indicates that productivity growth can benefit firms by allowing them to increase their mark-up rates. Indeed, firms face a lower growth rate of unit labor costs due to the direct effect of productivity on costs and its indirect effect on the nominal wage dynamics through the labor market. Also, an increase in the sensitivity of firms to changes in unit labor cost (ν_3) has a negative effect on the wage share. We expected that this effect was neutral, since this sensitivity can either benefit firms or workers. Its negative effect probably reflects a tendency of productivity growth being more relevant than nominal wage growth, which benefits firms. Finally, reflecting the observed relation between the innovation dynamics and the personal income distributions, figure 10c shows that the income Gini coefficient tends to increase when the innovation easiness increases (ζ). Conversely, the income Gini coefficient tends to decrease when the propensity to consume out of capitalists income increases. This is likely the case because higher consumption increases output and reduces the unemployment rate, which leads to a reduction in the personal income inequality (as explored in figure 5a).



(a) Output growth rate (b) Wage share (c) Income Gini coefficient

Figure 10: Global sensitivity analysis: response surfaces

Note: Monte-Carlo runs: 100. Time series refer to simulation effective periods. Dot identifies baseline specification and squares identify the maximum and minimum values. Input variables: innovation_change = x, innovation_easiness = ζ, sensitivity_mark_up_costs=ν_3, propensity_consume_income_capitalist=c_2^{cap} .

8 Conclusions

This article proposed a new agent-based macroeconomic model inspired by the post-Keynesian literature, in particular the neo-Kaleckian approach to income distribution. Its aim was to study the effect of two aspects related to the recent trends of increasing income inequality, namely the changes in institutions that support workers' bargaining power and productivity growth. These factors have been associated with the decreasing wage share and increasing wage-productivity gap, thus revealing that the dynamics of firms' mark-ups over costs was also a relevant factor in the process (De Loecker et al., 2020). Indeed, productivity growth can be an opportunity for firms to increase their profit margins and thus represents an increase in firms' strength. Nevertheless, its effect is mediated by workers' bargaining power, which is a counteracting force to that of employers. Therefore, the income distribution dynamics results from this interplay between productivity, mark-up rates and nominal wages.

The model structure reproduces a number of stylized facts concerning the macro and micro dynamics. It also reproduces important stylized facts concerning the functional and personal income distributions and the wealth distribution that have been relatively less explored in the agent-based modeling literature so far. In this sense, it offers a sound basis for the study of the income distribution dynamics. The model was employed to assess the effects of technological innovation and workers' bargaining power. We observe that when workers' strength in the bargaining process increases, there is a reduction in inequality and an increase in the output level. With respect to the innovation dynamics, we observe that the scenarios with higher capital good firm's search capabilities are associated with an increase in inequality, higher output levels and higher unemployment rates. Thus, the interaction between productivity growth and workers bargaining power indicates that the relation between the wage share or income inequality with output will depend on the source of distributional shock. If the source of economic stimulus is mainly associated with the innovation dynamics, there may be negative consequences in terms of the income distribution, as productivity growth is an opportunity for firms to increase their profit margins. Yet, if there is an increase in workers' bargaining power, firms will be forced to share productivity gains with workers and the higher output level will be associated with the higher wage share and lower personal income inequality. The results also highlight that the coupled dynamics of unemployment rates and output levels crucially depends on firms sharing productivity gains with consumers, so we always find a negative relation between the wage share and unemployment rates.

In conclusion, by highlighting the possible negative effects of productivity growth on the income distribution, our results suggest the possibility of a policy dilemma between promoting productivity growth and improving income equality. This sheds light on the mechanisms explaining the recent trends in income inequality observed in many economies, since changes in labor market institutions that reduced workers' strength (e.g., changes in union density, collective bargaining coverage, or minimum wage adjustments) in a context of productivity growth allowed firms to increase their mark-up rates. Yet, we also find that this trade-off is relatively weaker if workers' bargaining power is increased simultaneously to the higher innovation dynamics. In this case, there will be a higher wage share, lower income inequality, lower unemployment rate and even a higher output level than when only innovation is stimulated. Thus, while this combination does not fully offset the consequences of productivity growth on inequality, it does indicate a path for (partially) (re)conciliating different policy objectives by combining policies and institutions that sustain workers' strength with policies that stimulate innovation and productivity growth.

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Appendix A: Transaction flows matrix

The interactions between the agents are represented by the transaction flows matrix in table A.1. Aggregate values are calculated before the entry and exit of consumption goods firms takes place. These aggregate values are used to evaluate the consistency of the model by checking if the relations expressed by table A.1 hold. We also check the consistency of real and nominal output from the income, expenditure, and production approaches.

Table A.1: Transaction flows matrix

	Households	Consumption goods firms		Capital goods firm		Bank	Public sector	$\sum$
		Current	Capital	Current	Capital			
Consumption	$-C^{\$}_{H,t}$	$+Q^{s,\$}_{C,t}$						0
Investment			$-I^{\$}_{C,t}$	$+Q^{\$}_{k,t}$				0
Inventories		$+\Delta Q^{IN,\$}_{C,t}$	$-\Delta Q^{IN,\$}_{C,t}$					0
Wages	$+W^{\$}_{H,t}$	$-W^{\$}_{C,t}$		$-W^{\$}_{k,t}$			$-W^{\$}_{g,t}$	0
Profits	$+\Pi^{h,\$}_{H,t}$	$-\Pi^{n,\$}_{C,t}$	$+(\Pi^{n,\$}_{C,t} - \Pi^{h,\$}_{C,t})$	$-\Pi^{n,\$}_{k,t}$	$+(\Pi^{n,\$}_{k,t} - \Pi^{h,\$}_{k,t})$			0
Unemployment dole	$+d^{\$}_{H,t}$						$-d^{\$}_{H,t}$	0
Taxes	$-\mathcal{T}^{\$}_{H,t}$						$+\mathcal{T}^{\$}_{H,t}$	0
Loan interest		$-i\Lambda^{\$}_{C,t-1}$				$+i\Lambda^{\$}_{C,t-1}$		0
Deposit interest	$+iD^{\$}_{H,t-1}$	$+iD^{\$}_{C,t-1}$		$+iD^{\$}_{k,t-1}$		$-iD^{\$}_{b,t-1}$		0
Bonds interest						$+iB^{\$}_{t-1}$	$-iB^{\$}_{t-1}$	0
Change in loans			$+\Delta\Lambda^{\$}_{C,t}$			$-\Delta\Lambda^{\$}_{C,t}$		0
Change in deposits	$-\Delta D^{\$}_{H,t}$		$-\Delta D^{\$}_{C,t}$		$-\Delta D^{\$}_{k,t}$	$+\Delta D^{\$}_{t}$		0
Change in bonds						$-\Delta B^{\$}_{t}$	$+\Delta B^{\$}_{t}$	0
$\sum$	0	0	0	0	0	0	0	0

Note: The subscripts H and C identify the aggregate values of the households and consumption goods firms sectors respectively. The $+$ sign identifies sources of funds and the $-$ sign identifies uses of funds.

Appendix B: Model initialization and parameters

The proportion of capitalists, indirect and direct workers reflect the Brazilian social structure reported by Baltar and Rolim (2018). Accordingly, the number of indirect workers and capitalists depends on the number of direct workers, as follows:

$$N^{ind} = \left\lceil \frac{N^{dir}}{n^{dir}} n^{ind} \right\rceil \tag{B.1}$$

$$N^{cap} = \left\lceil \frac{N^{dir}(1 - n^{dir} - n^{ind})/n^{dir}}{N^c + N^k} \right\rceil (N^c + N^k) \tag{B.2}$$

where N^{dir} is the number of direct workers, n^{dir} and n^{ind} are the proportion of direct and indirect workers respectively. The number of capitalists per firm is equal to $\rho_1 = N^{cap}/(N^c + N^k)$. The number of direct workers as public servants (L^{dir}_g) is given by a multiple n^g of the number of direct workers employed by the private sector in the model's initialization, while the number of indirect workers as public servants is given by $L^{ind}_g = L^{dir}_g \lceil N^{ind}/N^{dir} \rfloor$.

Workers' initial wages are set according to their class, as follows:

$$w^{dir,\$} = \varrho_1 w^{\$}_{min,0} \tag{B.3}$$

$$w^{ind,\$} = \varrho_2 w^{dir,\$} \tag{B.4}$$

where $\varrho_{1,2} > 1$ are parameters.

Consumption goods firms start with the same full capacity production level ($Q^{fc}_{c,0}$). It is assumed that the machines were produced between $t = -T^k/2$ and $t = 0$ and that their productivity rate differs by a factor $\varrho_3 > 0$ per period.[36] Thus, each firm has a heterogeneous set of machines, but, as this heterogeneity is equal for all firms, there is a homogeneous composition of the capital stock across firms. It is also assumed that firms' initial production and sales are equal to their desired capacity utilization level and that inventories are at the desired level. The capital goods firm's initial production is proportional to the number of capital goods owned by the consumption goods firms and their lifetime and it is assumed that there is no increase in productivity in the first time step.

The parameters in the baseline scenario are reported below:

Table B.1: Parameters and initial values in baseline scenario

Symbol	Description	Value
α, β	Beta distribution parameters (innovation) (sec. 4.1.1)	(3, 3)
γ_1	sensitivity of desired wage by workers to inflation (eq. 22)	1
γ_2	sensitivity of desired wage by workers to output growth rate (eq. 23)	1
γ_3	sensitivity of reservation wage to periods of unemployment (eq. 24)	0.05
γ_4	minimum difference between desired and reservation wages (eq. 24)	0.1
δ	entrant firms' expected sales share of sector average sales (C sector) (sec. 4.2.10)	0.5
ζ	search capability (K firm) (eq. 1)	0.18
ϑ	employees turnover share (sec. 4.6)	0.05
$\mu_{c,0}$	initial mark-up rate (C firms) (sec. 4.2.5)	0.7
μ_k	mark-up rate (K firm) (eq. 8)	0.6
ν_1	sensitivity of mark-up rate to market share (C firms) (eq. 15)	0.04
ν_2	mark-up deviation persistence (C firms) (eq. 16)	0.99
ν_3	sensitivity of mark-up deviation to unit costs (C firms) (eq. 16)	0.25
ν_4	sensitivity of market share to competitiveness (C firms) (eq. 18)	1
ρ_1	number of capitalists per firm* (sec. 4)	1
ρ_2	proportion of revenue to R&D (K firms) (eq. 7)	0.15
ρ_3	managers per direct workers (K firms) (eq. 6)	0.24
ρ_4	indirect workers per direct worker (C firms) (eq. 13)	0.28
ρ_5	indirect workers per direct worker at full capacity production (C firms) (eq. 13)	0.09
ϱ_1	initial ratio between direct workers wage and minimum wage (eq. B.3)	3

continued . . .

[36]For instance, if a machine is assumed to belong to a vintage from $t = -T^k/2$, its productivity will be equivalent to a ratio $(1-\varrho_3)^{T^k/2}$ of the productivity of a machine produced in $t = 0$.

...continued

Symbol	Description	Value
ϱ_2	initial ratio between indirect workers wage and direct workers wage (eq. B.4)	3
ϱ_3	initial productivity difference between vintages (Appendix B)	0.001
τ	tax rate on income (eq. 25)	0.05
ϕ	sensitivity of workers' bargaining power to employment rate (eq. 26)	0.9
$\omega_{1,2,3,4}$	sensitivity of expected demand to past demand (C firms) (eq. 9)	(0.4, 0.3, 0.2, 0.1)
b	payback rule threshold (eq. 4)	2
c_1	real consumption persistence (eq. 25)	0.9
$c_2^{dir,ind,cap}$	propensity to consume out of income (direct workers, indirect workers, capitalists) (eq. 25)	(0.95, 0.85, 0.7)
i	base interest rate (eq. 21)	0.002
$L_g^{dir,ind}$	workers hired as public servants * (sec. 4.5)	(287,116)
ms^{min}	minimum market share to stay in the market (C firms) (sec. 4.2.10)	0.0005
N^c	number of consumption goods firms (sec. 4)	200
$N^{dir,ind,cap}$	number of direct workers, indirect workers*, and capitalists* (sec. 4)	(1754,707,201)
$n^{dir,ind}$	percentage of direct and indirect workers in total population (Appendix B)	(0.67, 0.27)
n^g	proportion of public servants in total initial employment (direct workers) (Appendix B)	0.2
n^{IN}	desired share of inventories (eq. 10)	0.1
$n^{s,dir,ind}$	proportion of workers in survey (sec. 4.6.1)	(0.15, 0.3)
n^w	number of hiring rounds per open position (sec. 4.6.2)	1.5
$Q_{c,0}^{fc}$	initial full capacity production (C firms) (Appendix B)	80
Q_m^{fc}	machines production at full capacity (sec. 4.2.3)	2.5
R	maximum interest payments to cash flow ratio (sec. 4.2.8)	0.1
T^c	number of periods before a new firm can exit the market (sec. 4.2.10)	5
T^k	machines lifetime (sec. 4.2.7)	20
u^d	desired capacity utilization level (sec. 4.1.1)	0.8
$w_0^{min,\$}$	initial minimum wage (eq. B.3)	1
x	Beta distribution support parameter (sec. 4.1.1)	0.1

Note: $\star$ identifies values determined in the model's initialization. Section or equation numbers in parentheses indicate where the parameters first appears.

Appendix C: Performance comparisons

Table C.1: Average values: alternative workers' bargaining power regimes (ϕ) and innovation regimes (ζ)

	$\phi = 0.9 \mid \zeta = 0.18$ (Baseline)	$\phi = 0.6 \mid \zeta = 0.18$	p-val	$\phi = 0.9 \mid \zeta = 0.06$	p-val	$\phi = 0.6 \mid \zeta = 0.06$	p-val
Weight of surveyed wage in bargaining	0.7756	0.5050	0.0000	0.7814	0.0002	0.5051	0.0000
Average mark-up (C sector)	0.7010	0.8044	0.0000	0.6248	0.0000	0.7482	0.0000
Wage share	0.6568	0.6271	0.0000	0.6806	0.0000	0.6421	0.0000
Profit dividends to average wages	4.8439	5.4885	0.0000	4.4906	0.0000	5.3002	0.0000
Income Gini coefficient	0.4622	0.4878	0.0000	0.4454	0.0000	0.4823	0.0000
Wealth Gini coefficient	0.8109	0.8450	0.0000	0.7854	0.0000	0.8390	0.0000
Gini income capitalists coefficient	0.4302	0.3933	0.0000	0.4446	0.0001	0.3930	0.0000
Gini wages coefficient	0.2725	0.2677	0.0000	0.2676	0.0000	0.2671	0.0000
Output growth rate	0.0092	0.0091	0.6798	0.0050	0.0000	0.0046	0.0000
Productivity growth rate	0.0092	0.0091	0.5521	0.0050	0.0000	0.0046	0.0000
Inflation rate	0.0007	-0.0038	0.0000	0.0047	0.0000	-0.0004	0.0000
Unemployment rate	0.1192	0.1414	0.0000	0.1095	0.0000	0.1385	0.0000

Note: p-values refer to comparison with baseline scenario.