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Technological unemployment and income inequality: a stock-flow consistent agent-based approach

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JEL Codes: C63; D31; E21; E25.

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1 Introduction

After the striking evidence presented in Piketty and Saez (2003) and extended in Piketty (2014), it became widely acknowledged that the degree of income inequality has not only been increasing as a whole in most advanced economies, but also that the working rich have replaced the rentiers at the top of the income distribution in the United States. In this context, several empirical and theoretical attempts have been made in recent economic literature to connect this phenomenon to the sources of the 2008 crisis and the slow recovery of aggregate demand in its aftermath.

Studies on the relationship between household consumption, debt accumulation and macroeconomic instability include Dutt (2006), Barba and Pivetti (2009), Kumhof and Ranciere (2010) and Taylor (2010). Focusing on the role of the functional distribution of income, Palley (2012) and Setterfield (2012) have examined the unstable consequences of the fall in the wage share in the US since the 1980s. When it comes to the personal – rather than functional – income distribution, empirical work by Cynamon and Fazzari (2013) has shown that the upsurge in household debt in the 2000s is largely due to an increase in demand relative to disposable income of the bottom 95% of the income distribution in the US. Setterfield and Kim (2016) developed a theoretical model linking the rise in income inequality within the top 10% of income earners to the potential instability in the household debt-to-income ratios due to the presence of emulation effects in consumption behavior.

From a long-term perspective, the crisis has exacerbated the redistributive effects of technological progress and decline in the labor share of output. The relevance of a joint investigation of both factor shares and individual distribution is stressed by different empirical studies. For example Garcia-Peñalosa and Orgiazzi (2013) find evidence of correlation between the share of different income sources and their contribution to overall income inequality. Giovannoni (2010) links the evolution of the share of output to the increase in income inequality and poverty over a large sample of countries starting from the 80s and in some countries in the 90s.

On the theoretical side, Dafermos and Papatheodorou (2015) integrate the study of functional and personal income distribution in an aggregate stock-flow consistent model to study the contribution of the different sources of income to income inequality. Departing from the standard stock-flow consistent modeling strategy, they allow households to receive income from multiple sources in order to shed light on the relationship between macro-factors (functional distribution) and micro-factors (personal distribution).

Starting from such developments, this paper aims to build a framework for the study of the relationship between both the personal and the functional distribution of income, technological progress, household debt and the emergence of macroeconomic instabilities from both a short run and a long run perspective. It will do so by building a demand-driven stock-flow consistent agent-based model with Kaleckian features.

The stock-flow consistent approach, developed by Tobin (1969) and Godley and Lavoie (2007), focuses on the interaction between households, firm sector and the financial sector. By taking into account all flows of income between different sectors in the economy as well as their accumulation into financial and tangible assets, these models are able to trace the flows of credit and the accumulation of debt in the economy as a potential source of financial instability[1].

In recent years, a number of papers have proposed a micro-foundation of stock-flow consistent models by adopting an agent-based approach (Caiani et al, 2016; Dosi et al, 2012; Godin and Kinsella, 2012; Kinsella et al, 2011; Seppecher and Salle, 2015, among others). As argued by Caiani et al (2016), the integration of the two approaches allows the study of intra-sectoral interactions and the consideration of the relevant microeconomic factors (such as the agent distribution) within a consistent and comprehensive representation of the economic system.

Among the existing agent-based models that are more directly related to the present work, Russo et al (2016)[2] propose a model in which the access to consumer credit increases inequality and economic instability. Workers adaptively revise their satisficing wage depending on whether they were employed or not in the previous period, originating a Goodwin-type effect on the business cycle. Consumers are characterized by habit formation, as they set their target level of consumption to a level at least equal to the previous period. Russo et al (2016) find that the government can curb inequality and stabilize the economy, in particular by acting acyclically as employer on the labor market.

The series of models named as "Keynes-Schumpter" (Dosi et al, 2008, 2010, 2013, 2015, 2017) combine a Schumpeterial and evolutionary approach focused on technological change (in line with Nelson and Winter, 1982) with the principle of effective demand to study how aggregate demand can impact on the generation and diffusion of technological innovation. In these models, technological innovation is the stochastic result of firms' expenditure in R&D, and the mark-up on price regulates the functional distribution of income in a Kaleckian fashion. In particular, while the mark-up of capital producing firms is exogenously set, the mark-up for firms that produce consumption goods is a function of their market share. The models are capable of replicating a large number of stylized facts. Dosi et al (2013) find that a larger share of output going to profit increases unemployment and the volatility of GDP, while leaving substantially unchanged its growth rate. An active fiscal policy is more effective than monetary policy to smooth the cycle and reduce inequality, in particular for high income inequality levels.

Ciarli et al (2012) propose an agent-based model to study growth as the result of the interaction between technological innovation, firms' organizational structures and demand factors such as income distribution and consumption patterns. The firm sector is microfounded while the household sector is composed of classes associated to a given wage level according to their skills. Ciarli et al (2012) find that firms' organizational structure and heterogeneity in consumption preferences play a relevant role in firms' ability to innovate and thus in shaping market structures. The evolution of the firms' organization affects the income distribution across classes of households which feedbacks into the profitability of firms through consumption demand. The model replicates a number of stylized facts and offers interesting insights on the possible causes

[1]Besides allowing for formal Minskyan analyses of debt accumulation and financial fragility (Dos Santos, 2005), SFC models have recently been used to study the macroeconomic effects of shareholder value orientation and 'financialisation' (Van Treeck, 2009), as well as that of household debt accumulation (Kim and Isaac, 2010). For an exhaustive survey see Caverzasi and Godin (2015).

[2]See also Riccetti et al (2013a,b, 2016)

of growth differentials across countries.

This paper presents four main original contributions with respect to the cited literature. First, technological progress is fully demand driven, according to Verdoon's law (McCombie and Thirlwall, 1994) which is generally assumed in Post-Keynesian growth models (Dutt, 1990). This setting can provide an additional perspective to the study of the endogenous shifts in the functional distribution of income caused by technological progress with respect to the stochastic supply-side mechanism usually employed in evolutionary agent-based models. In our framework, a surge in demand leads to higher productivity growth due to increasing returns, and consequently to an increase in the profit share. Second, we introduce and measure the effects of social imitation to account for the different propensities to save among consumers with wage differentials. This "emulation" effect introduces an indirect interaction channel among households. Third, we propose a factor decomposition to study the different effects on inequality of the different sources of income. Finally, from a methodological point of view, we make use of advanced computational techniques for the multidimensional exploration of the parameter space in order to identify the best mix of fiscal and redistributive policies in different parameter settings.

The numerical analysis of the model provides three main insights: first, it assesses the possible destabilizing effects of technological unemployment and the related increase in the capital share of output; second, it quantifies how income and wealth inequality evolve and how the effects of the different income sources change during the business cycle and in the long run; third, it evaluates the effects of different combinations of fiscal and redistributive policies.

The paper is organized as follows. Section 2 presents the theoretical model, including all behavioral equations and underlying accounting identities. The results for a single run of the baseline model are analyzed in section 3. The same section introduces the factor decomposition and discusses the results of the analysis for the baseline model. Section 4 introduces the three variants of the model with technological progress which are characterized by, respectively: constant functional distribution of income, varying functional distribution, and varying functional distribution with no tax on wages. Section 5 presents the numerical analysis of these three variants of the model for the single run simulations and the factor decomposition. Section 6 reports and discusses the results of the analysis of the surrogate model for all the four different settings (without and with technological progress). Finally, section 7 offers some concluding remarks.

2 The baseline model

The economy described is composed of households, the firm sector, the banking sector and the government. As in the conventional neo-Kaleckian literature, prices are set as a mark-up over labor costs, investment behavior is determined independently, and production by the firm sector adjusts to the quantity they are able to sell. While the firm sector is modeled as an aggregate, the household sector is agent-based. In particular, workers earn income from wages (or unemployment benefits if unemployed) and distributed profit (if they own shares of firms). To finance their consumption target they can take up debt, whenever their disposable income and wealth are insufficient.

The financial sector is considered as an aggregate: its basic role is to provide loans, hence holding debt as an asset, and to create money deposits endogenously as liabilities. The interest rate on loans is set exogenously. Hence, the dynamics of household debt will only be analyzed from the demand side, abstracting from the role of the increase in the supply of credit and possible credit rationing. The government collects taxes and distribute benefits to unemployed workers.

2.1 The firm sector

The production function is a Leontief-type technology with constant coefficients to produce a homogeneous good that can be used for consumption or investment. Potential output is given by:

$$Q_t = min(\xi L_t, \gamma K_t) \tag{1}$$

where ξ and γ are labor and capital productivity, respectively.[3] Firms' investment is assumed to respond positively to demand and relative value of equities. The investment function in levels can be represented by:

$$I_t = \left[i_0 + \alpha \frac{u_{t-1} - u^*}{u^*} + \beta h_t \right] K_{t-1} \tag{2}$$

where i_0 is the autonomous investment rate, $u_t = Q_t/\bar{Q}_t$ is the actual degree of capacity utilization, u^* is the (exogenous) desired degree of capacity utilization by the firm and $\alpha, \beta > 0$ are constant parameters. The term $h_t = \frac{Pe_{t-1}E_{t-1}}{P_{t-1}K_{t-1}}$ is analogous to Tobin's q, and represent the ratio between market capitalization (price of equities P_e times the number of equities E) and the monetary value of the capital stock.

The law of motion for the capital stock is:

$$\Delta K = I_t - \delta K_{t-1} \tag{3}$$

where $0 < \delta < 1$ is the rate of capital depreciation.

Following Kalecki (1971), the price is set as a mark-up on nominal unit labor costs[4]

$$P_t = (1+\mu)\frac{w_t\, L_t}{Q_t} = (1+\mu)\frac{w_t}{\xi}. \tag{4}$$

where w_t is the average nominal wage rate of the workers employed at $t-1$, Q_t is total output, $L_t = Q_t/\xi$ is the number of employed workers, and μ is the mark-up rate.

As in Kalecki (1971), the mark-up rate is assumed to depend on structural characteristics of goods markets, such as the degree of industrial concentration, and on the

[3] We will focus our entire analysis in the region where the economy is not capital-constrained and output is below potential, so that $\bar{Q} = \gamma K$ and $Q < \bar{Q}$. Model parameters have been calibrated in the simulations such as to avoid that the capital constraint becomes binding after the burnout phase.

[4] See Rowthorn (1982), Dutt (1984) and Taylor (1985) for early models of growth and distribution in this tradition.

relative bargaining power of workers and capitalists. The labor share of nominal output Ψ is given by

$$\Psi = \frac{w_t L_t}{P_t Q_t} = \frac{1}{1+\mu} \tag{5}$$

The gross profit share of aggregate output Π will then be

$$\Pi = 1 - \Psi = \frac{\mu}{1+\mu} \tag{6}$$

Retained profits are computed as the difference between its gross profits and the portion Θ of profits distributed as dividend to shareholders. Put differently, $(1-\Theta)$ is taken as an exogenous retention rate. Since the flow of profits is given by a constant share Π of the firm sector's output by the mark-up rule, retained profits are given by

$$A_t = (1-\Theta)\Pi P_t Q_t \tag{7}$$

Whenever the flow of investment desired by the firm is higher than their retained profits in the period, it will seek external finance to cover the difference. In particular, the firm sector will finance its investment by issuing equity E at price Pe.[5] Alternatively, whenever retained profits exceed desired investment, the firm will buyback shares.

The amount of equities evolves according to

$$\Delta E_t = \left(P_t I_t - A_t\right)/Pe_t \tag{8}$$

The symbol Ω identifies the difference between the total value of assets and the total value of liabilities:

$$\Omega_{f,t} = P_t K_t - Pe_t E_t \tag{9}$$

2.2 The household sector

As opposed to the firm sector, which are studied as an aggregate sector, the treatment of households in the model is agent-based. Variables referring to single households are identified by the superscript j, while aggregate variables have no index.

2.2.1 Income and consumption

Household's gross income is composed of wages w (that add up to a share Ψ of total nominal output PQ) and a share of net profits distributed by the firm sector (that add up to $\Theta\Pi PQ$). Each household's disposable income Y^j is given by the difference between her gross income, taxes, and interest payments on her debt D^j (at rate i).

Disposable income Y^j for each household is thus defined as:

$$Y_t^j = (1-\tau_y)(w_t^j + \theta_{t-1}^j \Theta\Pi P_t Q_t) - i\, D_{t-1}^j + b^j P_t \tag{10}$$

[5] Since the focus of the paper is systemic financial fragility as the result of households' leverage, we implicitly assume that the firm sector is fully rationed on the credit market. This assumption does not imply a loss of generality, as a perfectly elastic supply of credit rules out any possible crowding out effect on the credit market.

where τ_y is the tax rate on income. The quantity θ^j is determined to the rule described below in subsection 2.4 such that $\sum_j \theta^j = 1$. The real unemployment benefit b is paid by the government and is equal to a fixed amount for all unemployed workers, such that

$$b_t^j = \begin{cases} b & \text{for unemployed workers} \\ 0 & \text{for employed workers} \end{cases}$$

Consumption spending will be a positive function of disposable income and gross wealth, as in standard stock-flow consistent models. The distinctive feature in the consumption decision is that consumption for each worker will be assumed, as in Carvalho and Rezai (2016), to also depend on the difference between their own wage w^j and the average wage $\bar{w}$, calculated over the entire population N. This feature captures empirical evidence that the consumption-to-income ratio is the higher, the lower is the household's personal income relatively to median income, or the more we move toward the bottom quintiles of personal income distribution as found in the same paper by Carvalho and Rezai. In other words, relatively poor consumers tend to spend a larger share of their total income due to relative consumption. The centrality measure in the wage distribution can also be interpreted here as the money value of a median consumption basket, which sets a consumption standard for all workers.[6] In order to have a formulation of the multiplier as neat as possible we choose the average wage as a centrality measure. Workers' consumption decision depends on wages net of taxes 'before' interest payments (see Setterfield and Kim, 2016, for a plausible theoretical justification of this specification). Accordingly the postulated consumption function is

$$\begin{aligned} C_t^j = (1-s)(1-\tau_y)[w_t^j + \theta_{t-1}^j \Theta\Pi P_t Q_t] \quad & + b_t^j P_t + \eta\ (\bar{w}_t - w_t^j) \\ & + (1-\tau_W)(1-\sigma)W_{t-1}^j - \phi D_{t-1}^j \end{aligned} \tag{11}$$

where $0 < s, \sigma < 1$ are the propensities to save out of household income and wealth, respectively, τ_W is the tax rate on wealth, and $0 < \eta < 1$ is the sensitivity to workers' average wage. Unemployed workers are assumed to spend in consumption goods all their unemployment benefit. We abstract from credit defaults and the term ϕD^j, with ϕ as a positive constant, represents possible credit constraints that consumers face as their stock of debt increases.

Total consumption C_t is thus given by:

$$\begin{aligned} C_t = \textstyle\sum_j^N C_t^j = \quad & (1-s)(1-\tau_y)(\Psi + \Theta)P_t Q_t + (N - L_t) b P_t + (1-\tau_W)(1-\sigma)W_{t-1} \\ & -\phi D_{t-1} \end{aligned} \tag{12}$$

2.2.2 Savings and wealth

Savings for each worker S^j are defined as the difference between their disposable income and consumption levels $S_t^j = (1-\tau_y)Y_t^j - C_t^j$. Workers accumulate debt whenever

[6]The consumption rule applies to all workers, employed and unempoyed. Therefore it is theoretically possible that an unemployed worker consumes more than an employed one, with a consequent increase in leverage for the former. This simplifying assumption allows for aggregation and closure of the model through the multiplier.

their negative savings are larger than their existing stock of wealth, and prioritize repaying debt (deleveraging) whenever they hold positive savings. As a consequence, a worker cannot have at the same time positive debt and wealth.[7]

Households' assets are money and equities. For simplicity deposits earn no interest. Assuming investors holding a fraction Λ_t of their wealth in shares we can write

$$Pe_t E_t^{jd} = W_{t-1}^{j} \Lambda_t \tag{13}$$

where E^{jd} is the quantity of shares demanded by household j. Each household measures the profitability of investment in equities according to the following function borrowed from Chiarella and Di Guilmi (2011)

$$\Lambda_t = \frac{1}{1 + exp[-\lambda V_{t-1}]} \tag{14}$$

where $\lambda > 0$ is a constant, and $V_{t-1} = \frac{\Theta \Pi P_{t-1} Q_{t-1}}{Pe_{t-1} E_{t-1}}$ is the rate of return of investment in shares. From (13) and (14) we have that

$$\frac{Pe_t E_t^{jd}}{W_{t-1}^{j}(1-\tau_W)} = \frac{1}{1 + exp[-\lambda V_{t-1}]} \tag{15}$$

Following Godley and Lavoie (2007), we consider that the share of wealth to be invested in equities is calculated on the previous year's wealth. The aggregate of equation (15) represents the demand for equity, which is given by

$$\sum_j E_t^{jd} = E_t^d = \frac{W_{t-1}(1-\tau_W)}{Pe_t} \frac{1}{1 + exp[-\lambda V_{t-1}]} \tag{16}$$

According to equation (8) and to Godley and Lavoie (2007, page 390), the supply of stocks is formulated as

$$E_t^s = E_{t-1} + \frac{P_t I_t - A_t}{Pe_t} \tag{17}$$

Accordingly, the clearing price in the equity market will be

$$Pe_t = \frac{1}{E_{t-1}} \left[\frac{W_{t-1}(1-\tau_W)}{1 + exp[-\lambda V_{t-1}]} - (P_t I_t - A_t) \right] \tag{18}$$

The change in wealth for the individual is then

$$\Delta W_t^j = \Delta Pe_t E_{t-1}^j + S_t^j - D_{t-1}^j \tag{19}$$

Wealth for each household is given by

$$W_t^j = \begin{cases} W_{t-1}^j(1-\tau_W) + \Delta W_t^j & \text{if } W_{t-1}^j(1-\tau_W) + \Delta W_t^j > 0 \\ 0 & \text{otherwise} \end{cases} \tag{20}$$

[7]The priority given to debt repayment follows from the assumption that money deposits do not hold any interest. Setterfield and Kim (2016) and Lusardi et al (2011) provide a theoretical explanation for this assumption based on a "pecking order"-type behavior of households.

Symmetrically, the law of motion for debt is:

$$D_t^j = \begin{cases} D_{t-1}^j - [W_{t-1}^j(1-\tau_W) + \Delta Pe_t E_{t-1}^j + S_t^j] & \text{if } D_{t-1}^j - [W_{t-1}^j(1-\tau_W) + \Delta Pe_t E_{t-1}^j + S_t^j] > 0 \\ 0 & \text{otherwise} \end{cases} \tag{21}$$

The amount of shares owned by investor j will evolve according to

$$E_t^j = E_t \frac{W_t^j}{W_t} \tag{22}$$

Due to the fact that each investor holds a different portfolio and each firm can have a different equity price, each investor will experience a different change in the value of her portfolio. This volatility is modeled by the idiosyncratic shock $\tilde{\rho}$, which is assumed to be normally distributed (as in Levy, 2003) with $\tilde{\rho} \sim \mathcal{N}(1, \sigma_\rho)$. Accordingly the share of profits of each worker will be given by

$$\theta_t^j = \frac{\tilde{\rho}_t^j Pe_t E_t^j}{Pe_t E_t} = \frac{E_t^j}{E_t}\tilde{\rho}_t^j \tag{23}$$

For a large enough number of workers the law of large numbers applies[8], hence $\sum_j E_t^j \tilde{\rho}_t^j = E_t$. We introduce this assumption for two main reasons. First, in line with Levy (2003), an idiosyncratic shock on wealth is the mechanism that generates a power law tail in the personal distribution of wealth. Second, it adds to the realism of the model, since it accounts for the heterogeneity of portfolios, which is averaged out in the aggregate firm sector. Eliminating the shock does not change the qualitative outcomes of the model in terms of cycles but reduces its capacity of replicating the empirical evidence of a power law tail in the distribution of wealth.

For households with positive wealth, money deposits are calculated as a residual:

$$M_t^j = W_t^j - Pe_t E_t^j \tag{24}$$

Hence, the the difference between the total value of assets and the total value of liabilities of each household is

$$\Omega_{h,t} = M_t^j + Pe_t E_t^j - D_t^j \tag{25}$$

2.2.3 Wage dynamics

Following Nirei and Souma (2007) and Russo (2014), the evolution of each worker's wage is determined by an additive process of the type

$$w_t^j = \begin{cases} w_t^{j*} = w_{t-\tau^j}^j(1+\pi^e) + \varepsilon_t^j w_{min,t} & \text{if } w_t^{j*} > w_{min,t} \\ w_{min,t} & \text{otherwise} \end{cases} \tag{26}$$

where π^e is a constant inflation rate embodied in job contracts, ε iid uniformly over a predetermined interval with $\mathbb{E}[\varepsilon] = 0$, and $w_{min,t} = w_{min,t-1}(1+\pi_t)$ is the nominal

[8] The numerical simulations confirm that in each period the accounting consistency is mantained.

minimum wage set by the government and updated in each period for the actual inflation rate π_t.[9] For workers who come from one period (or more) of unemployment, the salary on which the shock is applied is the last with a positive value and τ^j is the number of periods between the current and and the last one in which the worker was employed.

The number of unemployed workers is given by the difference between N, the total number of available workers, and the number of employed workers L_t. In the simulations, a fully random mechanism will determine which workers become employed or unemployed in each period of time.

2.3 The government

The government collects taxes from income and wealth and pays unemployment benefits. Given our focus on the household sector and the fact that we abstract from issues on debt sustainability, we consider only the taxes on personal income and assume away corporate taxation.[10] As a consequence reinvested profits are not taxable.

Total receipts by the government will thus be equal to:

$$T_t = \tau_y(\Psi + \Theta\Pi)P_t Q_t + \tau_W W_{t-1} \tag{27}$$

Assuming for simplicity that the government earns no interest on accumulated surpluses and pays no debt service, the government's wealth evolves according to

$$B_t = \Omega_{g,t} = B_{t-1} + T_t - bP_t(N - L_t) \tag{28}$$

When $B > 0$ the government holds a bank deposit, while when $B < 0$ the banking sector holds government bonds.

2.4 The financial sector

Banks are considered as an aggregate sector. It gives loans to workers, hence holding their debt as an asset, and creates money deposits endogenously as liabilities. It receives an interest rate i on workers' loans. Banks also buy government bonds or keep government deposits. Interest receipts from worker loans allow the financial intermediary to increase the difference between the total value of assets and the total value of liabilities. Since we abstract from defaults in the firm sector the law of motion for the financial sector is given by:[11]

[9] Due to (4), the actual inflation is always roughly equal to π^e as confirmed by simulations.

[10] Given that the main focus of this paper is household leverage in the presence of technological progress, we abstract from unnecessary complications, such as the inclusion of a government budget constraint or the study of the sustainability of public debt. In the simulations, we do not observe in any scenario an explosive dynamic of debt. When its absolute size grows, the system collapses before public debt goes out of control. The introduction of a range in public debt would negatively affect aggregate demand and lead to an earlier collapse, without changing the underlying conclusions and the basic intuitions.

[11] Systemic financial fragility can be further analyzed by extending the model to include microfounded firms and banks. However the introduction of the negative term ϕD_{t-1} in equation (11) partially addresses this shortcoming. The accumulation of debt progressively reduces consumption and aggregate demand, replicating in substance the effect of a debt default.

$$\Omega_{b,t} = (1+i)D_t - B_t \tag{29}$$

2.5 Goods market equilibrium

As the economy is below potential, nominal output PQ is determined by aggregate consumption C and total investment I.

$$P_t Q_t = C_t + P_t I_t \tag{30}$$

After substituting C_t from (12), using (4) and solving for Q we obtain:[12]

$$Q_t = \mathscr{M}\{I_t + \frac{W_{t-1}}{P_t}(1-\sigma)(1-\tau_W) - \phi\frac{D_{t-1}}{P_t} + Nb\} \tag{31}$$

where $\mathscr{M}$ is the multiplier given by

$$\mathscr{M} = \frac{1}{[1-(1-s)(1-\tau_y)(\Psi+\Theta)] + \frac{b}{\xi}} \tag{32}$$

The multiplier is directly proportional to the propensity to consume, the share of distributed profits, the wage share of income, and the productivity of labor. It is negatively related to the tax rate and the real unemployment benefit (since the weight of b in the production function positively depends on unemployment).

Table 1 shows the balance sheets of each sector: firm sector, households, government and banking sector.

Firms		Households		Gov.		Banks	
PK	P_eE	M	D	B		D	M
		P_eE					B
	Ω_f		Ω_h		Ω_g		Ω_b

Table 1: Units and sectoral balance sheets.

3 Numerical Analysis of the Baseline Model

Simulations were performed using Matlab. In the benchmark scenario the values of the parameters are: $\alpha = 0.55; \beta = 6; \delta = 0.015; u^* = 0.8; \xi = 0.05; \sigma = 0.5; s = 0.25; \eta = 0.5; i_0 = 0.1; w_{MIN} = 25; i = 0.035; \pi^e = 0.035; \Theta = 0.8; \mu = 0.8; b = 0.08; \varepsilon \in [-0.125; 0.125]; \sigma_\rho = 0.2; N = 5000$. Initial values for wages, debt and capital for each agent are randomly

[12] Equation (31) simply represents the accounting closure of the demand-driven model in order to determine the aggregate level of output as in standard textbook Keynesian models.

drawn from uniform distributions. The parameters are calibrated with the aim of reproducing realistic outcomes at the micro-level within a cyclical macroeconomic behavior.[13] The depreciation rate is similar to the level that can be found in other models within the agent-based literature[14] (Chiarella and Di Guilmi, 2011; Dawid et al, 2014), and the level of the desired capacity utilization u^* is similar to what detected by the empirical literature and adopted in many SFC models (Godley and Lavoie, 2007; Lavoie, 2014). The simulation codes are available upon request.

3.1 Single run results

Figure 1 presents the results for a single run. In the absence of productivity growth, aggregate demand oscillates around a horizontal trend. Boom and bust episodes of duration around 15-20 periods are visible. The values of the Gini indexes are close to 0.8 and 0.5 for wealth and income, respectively, and comparable to the ones empirically observed in the US economy (0.8 and 0.4, respectively, from NBER and OECD data). The values of the Gini index for salary produced by the simulation is around 0.5 (slightly higher than the one empirically detected, which is close to the value for income). The correlation between output and financial variables (in real term) are as expected. Real wealth is positively correlated with output (with one period lag) while the aggregate leverage ratio appears to be negatively correlated with output (with one period lag). The government wealth moves together with output. The results of the simulations are not sensitive to the total number of households.

Looking at the Gini indexes, wage inequality is higher than overall income inequality.[15] Inequality in wealth, wages, and income of employed workers decreases during expansions while inequality in overall income appears to be more aligned with the cycle. The gap and the different patterns between income of employed workers and overall income is due to the presence of unemployment benefits. The factors behind the dynamics of the Gini indexes can be identified by looking at the micro-level distributions, which provide a level of detail that the aggregate measure is not able to capture. Both income distribution and wealth distribution have fat tails and can be approximated by a Pareto CDF (figures 2 and 3) as detected by the empirical literature. The graphical analysis exploits the algorithm introduced by Clementi et al (2006), in which the identification of the threshold parameter for the Pareto tail is data driven. Interestingly, for both variables the distribution changes shape moving from the peak to the trough of the cycle. More precisely, the Pareto distribution for income at the peak of the cycle is shifted to the right and steeper than the one at the trough. The plot reveals that, during expansions, workers move from a part of the distribution that we can define as *lower middle-class* to another with higher income that we can define as *upper middle-class*, and the right tail of the distribution becomes steeper. Hence, the increase

[13]The generation of macroeconomic patterns more aligned with the empirical evidence would require a specific analysis of real data and the use of more sophisticated calibration techniques which, given the length and the scope of the present paper, we prefer to postpone to future developments of this project.

[14]Other agent-based models (for example Caiani et al, 2016; Dosi et al, 2015) use a higher value of 5%. This parameter is not central in our model and its effect is mostly to increase the frequency of fluctuations.

[15]This outcome is due to the high heterogeneity of wages and their dynamics. The unemployment benefit is the major factor in reducing the overall income inequality.

in the Gini coefficient observable during expansions is mostly due to movements in the central part of the distribution which increase dispersion. This conclusion is further supported by the analysis of the evolution of the Gini coefficients for different quintiles of the income distribution. The correlation between the Gini index and the unemployment ratio is positive for the bottom two quintiles and negative for others, showing that unemployment shocks hit more severely the low-income households, due to their reliance on wage earnings, in line with the empirical results in Atkinson et al (2011) and Hoover et al (2009). The variants of the model with technological progress discussed below produce comparable scenarios when looking at the correlations of the different quintiles with economic activity. Turning our attention to the wealth distribution in figure 3, it appears that the decrease in the Gini index that occurs during expansions is mostly due to wealth being more evenly distributed *within* the upper tail and thus does not imply a redistribution of wealth from the top to the bottom of the distribution.

The accumulation of capital drives the expansionary phase through higher levels of capacity utilization and lower unemployment which boosts consumption expenditure. At this stage, larger investment by the firm sector can be financed as the generation of profits and the high levels of employment ensure a sufficient demand for equities and, consequently, increase in asset price (as testified by the positive correlation between Q and P_e). The high levels of aggregate demand and employment causes a generalized growth in wages, reducing disparities across wage earners. This also leads to an increase in the average wage, inducing more households to resort to credit to finance consumption thanks to the emulation effect. The service of debt reduces their net income, worsening their financial positions and preparing the stage for the subsequent bust. Those who can entirely finance their consumption with their income accumulate equities, further boosting their profit income in a virtuous cycle. The contemporaneous increase in leverage for some households, and in profit income for the others explains the positive correlation between the Gini index for non-wage income and aggregate demand. Towards the peak of the cycle, the accumulation of debt starts reducing consumption while aggregate savings dwindle, causing a reduction in equity price. Lower demand and lower stock market capitalization constrain investment, leading to a bust. While the aggregate level of consumption decreases, households with savings can collect a large number of shares on the market, due also to the lower prices. Unemployment raises, widening the gap between those who own assets and those who do not. At the same time, the increase in unemployment compresses the average wage, reducing consumption and increasing the actual saving rate for those earning a wage above the mean. When enough savings are accumulated, the increase in the net wealth of the economy will prompt another boom.

3.2 Factor decomposition

Further insights on the evolution of income inequality during the cycle can be gained by applying the decomposition technique introduced by Shorrocks (1982). This method identifies the relative contributions of the different income sources κ to inequality as

$$s_\kappa = \frac{cov(Y_\kappa, Y)}{var(Y)} \tag{33}$$

where Y_κ is the income coming from source κ. Considering that the size of the unemployment benefit is the same for each recipient, we can focus on the three other sources of income in equation (10): wages, profits and interest on debt (as a negative factor). Figure 6 shows that the contribution of profits is slightly higher than the one from wages. The relative sizes of the different effects is sensitive to the percentage of distributed profits, quantified by parameter Θ which is set at 0.8 in this representative simulation, while the cyclical patterns are not affected.

The profit effect is larger during expansions while the wage effect is negatively correlated with output, showing that the pro-cyclicality of the Gini index for aggregate income is due to the profit component, also considering the fact that the index for wages is anti-cyclical. Debt effect has a relatively small impact and displays a negative correlation with output, revealing that the dynamics of leverage distribution is one of the causes of the phase transitions in the business cycle. Different single run simulations demonstrate that changes in the level of social imitation η do not substantially change the proportions of the different income sources. An increase in the tax rate for income increases both effects, with the wage contribution showing the largest variation thanks to a sizable increase in the Gini coefficient. Changes in the tax rate for wealth, unemployment benefit and minimum wage do not substantially alter the results of the factor decomposition.

Following the applications of Shorrocks's decomposition presented in Dafermos and Papatheodorou (2015) and Garcia-Peñalosa and Orgiazzi (2013), it is possible to quantify the absolute contribution of each source of income to inequality measured by the squared coefficient of variation. The squared coefficient of variation is given by

$$C^2 = [Var(Y)/\bar{Y}]^2$$

where $\bar{Y}$ is the average income. The absolute contribution is indicated as S_k^C and calculated as follows

$$S_k^C = s_k * C^2 \tag{34}$$

The sum of the three components is the value of the squared coefficient of variation. The squared coefficient of variation can be more informative than the Gini index for this investigation because it has no upper limit. The graphical analysis of the bottom panel of figure 4 reveals that the dispersion in profits is again the main factor in explaining income inequality and appears to be more volatile. Also in this case the relative sizes of profit and wage effect is regulated by the parameter Θ.

Both wage effect and profit effect display a higher correlation in absolute term with the cycle, with the same signs as in the analysis of the absolute effect. Bearing in mind that the squared coefficient of variation is more sensitive to concentration in the top of the distribution as opposed to the Gini index which is more sensitive to the middle of the distribution, the increase in volatility confirms the conclusions of the analysis discussed above: the upper tail of the distribution is more sensitive than the rest of the population to cyclical variations in aggregate demand. Changes in the parameters affect the absolute weights in the same way as in the relative decomposition.

4 Models with technological change

In the existing agent-based literature on the impact of technological change on income distribution (such as Dosi et al, 2010, and the following Keynes-Schumpeter models), increases in productivity are the stochastic outcomes of the firm sector's effort and profitability, and the effect of aggregate demand depends on the market structure. In this paper we propose a mechanism according to which the rate of technological progress is dependent on the rate of capacity utilization.The positive response of the growth rate of labor productivity to the level of economic activity is the basis of Verdoorn's Law, which assumes increasing returns to scale in production. In the Kaldorian tradition, a positive response of labor productivity to economic growth is also justified based on the idea that investment by the firm sector tends to incorporate more advanced technologies in the new machines. [16]

4.1 Technological progress with constant functional distribution of income

Labor productivity is assumed to be time-varying according to a mechanism adapted by Hein and Tarassow (2010). They theorize and empirically verify across different countries that the variation in labor productivity depends positively on the rate of growth in capacity utilization (as in Verdoorn's law), and negatively on the share of profits. We focus on the former, since in our model the effect on demand of a change in the profit share is already accounted for by the different propensities to save for profits and wages. Indicating with a hat the percentage change, the variation in the productivity of labor is assumed to be

$$\hat{\xi}_t = \begin{cases} \gamma_1 \hat{u}_{t-1} & \text{if } \hat{u}_{t-1} > 0 \\ 0 & \text{otherwise} \end{cases} \tag{35}$$

where γ_1 is a positive constant.[17]

Three variants of the model with technological progress are examined. The first one is exactly equal to the baseline model but with a varying productivity of labor as determined by (35). In the second one, the functional distribution of income reacts to unemployment: a larger (smaller) unemployment is assumed to increase the bargaining power of employers (workers), and as consequence the share of output going to profits increases (decreases). In the third scenario, we modify the taxation mechanism.

[16] Also Ciarli et al (2012) refer to Verdoorn's law, but only as a positive correlation between output and technical change that they find *ex-post* in their simulation data, while the determinant of the latter is on the supply side as in the cited Keynes-Schumpeter models and in other Schumpeterian growth models such as Silverberg and Lehnert (1993).

[17] For simplicity, we abstract from the cost of innovation because the firm sector is modeled as a single aggregate and the R&D costs for one firm would be the revenue for another in a stock-flow consistent perspective. A more refined modeling of the innovation financing process would imply the modeling of an additional capital or innovation producing sector as in the cited agent-based models or in aggregate models such as Caiani et al (2014) for example. Since the paper focuses on the effects of technological progress on household income distribution this aspect is left to possible future developments of this research.

4.2 Technological unemployment and varying functional distribution of income

It is well known that in the US and in the majority of industrialized countries from the middle of the 1980s, real wages have not kept the pace with productivity, shifting the functional distribution of income towards profit (see for example Giovannoni, 2010; Stockhammer, 2013). While a number of reasons have been addressed to explain this piece of evidence, in order to link the effects of technological progress on the functional distribution of income in our stylized model, we assume that the bargaining power of capitalists (workers) is directly (inversely) related to the change in the unemployment ratio in a Goodwin-style mechanism of cyclical growth (Goodwin, 1967).[18] According to this mechanism the labor saving technological progress generates unemployment which, in turn, increases the share of output going to profits.

The functional distribution of income is determined by the price mark-up, which in this variant of the model will evolve according to

$$\mu_t = \mu_{t-1}(1+\gamma_2 * \hat{un}_t); \tag{36}$$

where $\hat{un}$ is the relative variation in unemployment and $\gamma_2 > 0$ quantifies the sensitivity of the functional distribution to job market conditions and therefore reflects the efficiency of bargaining institutions. Such assumption allows the introduction of varying functional distribution of income in an otherwise standard Kaleckian setting. Accordingly the shares of output going to wages and profits are now given by

$$\Psi_t = \frac{1}{1+\mu_t}, \tag{5-bis}$$

$$\Pi_t = \frac{\mu_t}{1+\mu_t} \tag{6-bis}$$

The other relevant equations of the baseline model change accordingly, with time-dependent Ψ_t and Π_t.

4.3 Zero tax on wages

A further variant that we test involves the change in taxation and, specifically, different taxation rates for profits and wages. For simplicity, we assume that wages are not taxed and that τ_y is now the taxation rate on distributed profits.[19] Accordingly, we have the following modification in the model's equations

$$Y_t^j = w_t^j + (1-\tau_y)(\theta_{t-1}^j \Theta \Pi P_t Q_t) - i\, D_{t-1}^j + b^j P_t \tag{10-bis}$$

$$C_t^j = (1-s)w_t^j + (1-s)(1-\tau_y)[\theta_{t-1}^j \Theta \Pi P_t Q_t] \quad + b_t^j P_t + \eta\, (\bar{w}_t - w_t^j) \\ + (1-\tau_W)(1-\sigma)W_{t-1}^j - \phi D_{t-1}^j \tag{11-bis}$$

[18]Such predator-prey dynamics between demand and distribution are studied for instance in Skott (1989) and Barbosa-Filho and Taylor (2006).

[19]An alternative solution to introduce a more progressive tax system would involve, for example, different rates for brackets of income earners. However this option would make impossible to calculate the multiplier and have a neat and simple closure of the model as the one presented in section 2.5.

$$C_t = [(1-s)\Psi + (1-s)(1-\tau_y)\Theta]pQ_t + (N-L_t)bP_t + (1-\tau_W)(1-\sigma)W_{t-1} - \phi D_{t-1} \tag{12-bis}$$

$$T_t = \tau_y \Theta \Pi P_t Q_t + \tau_W W_{t-1} \tag{27-bis}$$

$$\mathscr{M} = \frac{1}{[1-(1-s)\Psi-(1-s)(1-\tau_y)\Theta] + \frac{b}{\xi}} \tag{32-bis}$$

5 Numerical Analysis of the Model with Technological Progress

This section discusses the results of the simulations for the three variants of the baseline model introduced in section 4. The parameter setting is as presented in section 3 with the additional parameters $\gamma_1 = 0.05, \gamma_2 = 0.3$. The values for the parameters $\xi = 0.1$ and $\mu = 0.8$ used in the simulations of the baseline model are here used as initial values.

5.1 Technological progress with constant functional distribution of income

Figure 5 plots the result of a single run of the model with productivity dynamics as in equation (35). Also in this case a clear cyclical pattern emerges but with a few differences from the baseline scenario. Output, unemployment and debt all display an upward trend and the cyclical pattern appears to be more regular. Moreover, as the simulation progresses the volatility and the length of the cycle increase: bubble and bust become larger in amplitude and longer in duration. If we let the simulation run long enough, eventually unemployment reaches 100% and the system collapses. The crash can be delayed by a lower initial level of the technological parameter ξ, a lower Θ which determines a more even functional distribution of income, and a higher unemployment benefit b. In particular for values of b high enough ($b \geq 0.5$ for this particular parameter setting), the economy stabilizes at very low unemployment and constant level of public debt. A higher tax rate on income reduces the amplitude of fluctuations but, as it reduces demand and increases unemployment, is not able to delay the crash. Higher levels of minimum salary do not impact on the evolution of the economy and do not appear to be able to avoid or delay the crash. Finally, the amplitude of the swings in production and unemployment appear to be positively correlated with the level of the imitation parameter η.

The signs of the correlation coefficients between the Gini indexes and aggregate demand are the same as in the baseline scenario, and also the shifts of the income and wealth distributions over the cycle are substantially similar to the previous case. Losses and gains during the different phases of the cycle are unevenly distributed across income classes, as demonstrated by the analysis of the quintiles, which shows decreasing concentration in the bottom four quintiles and increasing concentration in the top one during expansions.

The factor decomposition (figure 6) reveals interesting differences with the baseline model. The evolution of the three factors display the same increase in volatility as the variables in figure 5. The correlation between their effects and the business cycle is reversed from the baseline model. Indeed, while the effect of profits is still dominant, the weight of wages increases during expansions. This is possibly due to the increasingly wider fluctuations with a large share of unemployed workers, whose wage has not been updated for one or more periods, becoming employed and hence subject to a relatively substantial idiosyncratic shock, which in turn has kept up with inflation. Modifications in the parameter setting have the same effects discussed in the case of the baseline model.

5.2 Technological unemployment and varying functional distribution of income

Figure 7 illustrates the results for the simulation of the model with technological progress and functional distribution of income varying according to (36). The pattern is similar to the one observed for the case of constant functional distribution: upward trend for output, unemployment, and debt, together with increasing volatility and periodicity of the cycle. Also in this case the economy collapses as unemployment eventually reaches 100%. Due to the growing factor share of capital, the weight of profits in overall inequality increases over time, as shown by figure 8. Inequality in the distribution of profit income increases during expansions and explains the fact that in this scenario also the Gini indexes for wealth and income of active workers show a slightly positive correlation with the cycle.

The Gini indexes calculated within the second and third quintiles of the income distribution have a strong positive correlation with the unemployment rate whereas the indexes for the top two quintiles are negatively correlated with unemployment. The correlation for the bottom quintile is close to zero because during recessions for most of the households in that cohort the only income is given by the unemployment benefit.

The complete sensitivity analysis is presented below in section 6. However, different simulations with different values of the fiscal policy parameters (minimum wage, tax rates and unemployment benefit) show that, for this particular parameter setting, the most effective policy tool is the unemployment benefit, which can sustain aggregate demand, reducing at the same time aggregate leverage and inequality for all the three measures. The larger government expenditure in this case would be compensated by an increase in the fiscal revenue, leaving the government deficit substantially unchanged from the levels depicted in figure 7. Increasing only the tax rate has a depressive effect on economic activity.

The factor decomposition (figure 8) shows that almost all the dispersion in income is due to profits. This outcome is particularly evident for the relative effects, displayed in the bottom panel. In this case the effect of profits is pro-cyclical while those of wages and debt are counter-cyclical. This pattern can be explained by the fact that, due to the presence of technological unemployment, the wage effect is dominated by the increasing profit effect due to a functional distribution of income progressively more geared towards capital. An increase in the unemployment benefit substantially reduces the weight of profits, while pushing that of wages towards zero. At the same time both series would be less volatile.

5.3 Technological unemployment, varying functional distribution of income, and zero tax on wages

If wages are not taxed and τ_y becomes the tax rate on profits, the economy can reach full employment. Figure 9 shows that the economy grows at a steady pace, with full employment, and a sustainable path for public and private debt. However, also in this case the economy is vulnerable to sudden crashes as the one that occurs at period 483 in this simulation, with a dramatic drop in output and unemployment that raises above 20%. The better performance in this scenario is due to stronger demand, since the totality of wages constitute disposable income, and to the higher multiplier.

Inequality in wages decreases during expansions while inequality in wealth and income are basically uncorrelated with the cycle. Given that the economy is almost always at full employment, the Gini index for income of employed workers coincides with the one for overall income. Fluctuations are significantly milder than in the other scenarios; however also in this case the business cycle has a different impact on the various cohorts of income distribution. In fact, a recession determines a generalized loss of income, except for those at the top 1% who increase their earnings. A possible cause of this is the accumulation of shares by debt-free households during a recession due to the low price of shares, when the other households are engaged in de-leveraging and have no financial resources available to invest in stocks.

Both wealth and debt display a strong positive correlation with aggregate demand. At the peaks of the business cycle the accumulation of debt reaches a critical threshold and determines a substantial decrease in consumption, triggering a recession and a relatively slower accumulation of wealth by the richest households.

The sudden crisis can be triggered by simultaneous negative shocks on wealth hitting some of the richest households and not compensated by positive shocks for the less wealthy, determining a sharp decline in the stock price. In the simulation depicted in figure 9, the crash is preceded by a large stock market boom and bust. Due to the delay in the consumption function, consumers do not adjust immediately to the new lower level of wealth and the consequent increase in their leverage is magnified by the imitation effect. In the following period, autonomous expenditure will drop due to the stock market crash, which negatively impacts on the firm sector's investment, and consumption will be cut due to the previous increase in the stock of debt. Other single run simulations of this model reveal that when these episodes become recurrent, the economy can collapse as in the other scenarios.

The factor decomposition (figure 10) shows a very regular pattern with anti-cyclical wage and debt effects and pro-cyclical profit effect. Differently from the other scenarios, unemployment is constantly at 0 in this simulation and the relative change in weights of the different factor can only be explained by the fact that during expansions the accumulation of wealth for some households and the piling up of debt for the others are both faster, determining a more uneven distribution of profits.

In this setting, the tax rate can actually help in reducing income inequality by partially re-balancing the dynamics of the functional distribution of income. Looking at the factor decomposition, a higher tax rate on profits reduces their weight both in absolute and in relative terms. As a consequence, the effect of wages can be larger than the effect of profits for the same level of Θ, in particular during recessions.

In order to verify that the decrease in unemployment is actually a result of the redistribution of the fiscal burden rather than simply an effect of the possibly lower amount of taxes, we run simulations of the model of section 4.2 with lower tax rates on income. Figure 11 shows the results for $\tau_y = 0.05$, and reveals that despite the fact that the economy can occasionally achieve full employment, volatility and financial distress increase over time.

Figure 12 contrasts the different dynamics of labor productivity and real wage generated by the models in sections 4.2 and 4.3. For the model of section 4.2, the increase in unemployment determine a divergent dynamics which leads to the system's collapse when the unemployment ratio tends to 1 and the real wage to 0. A taxation system that favors wage earners is able not only to generate real wage growth but also a higher level of productivity (thanks to a generally higher aggregate demand). Figure 12 also shows that in order to generate an almost constant real wage (comparable to the one recorded for the US in the last 45 years), the parameter γ_2 must be set to a value of 0.03.

6 Sensitivity analysis

The parameter space is explored by means of the SUrrogate MOdeling (SUMO) Toolbox (Gorissen et al, 2010) for Matlab.[20] This toolbox allows the study of joint variations in the parameters and can be exploited in our investigation for identifying the best policy mix in order to curb inequality and stimulating growth. The exploration of a multi-dimensional parameter space would imply running a prohibitively high number of Monte Carlo simulations. The issue is overcome by building an alternative representation of the agent-based model, called surrogate model or meta-model. The toolbox iteratively selects the data generated by the simulations randomly sampling the parameter values within intervals set by the modeler, and identifies a pre-defined number of surrogate models by estimating a relationship between the different inputs (the parameters) and the outputs (a set of variables identified by the modeler). The surrogate model that minimizes the error measure(s) is eventually selected and used in the sensitivity analysis. A more technical discussion of global sensitivity analysis in agent-based modeling goes beyond the scope of the present paper but for further details we refer the reader to Saltelli et al (2008), and to Salle and Yildizoglu (2014) for a specific application to an economic agent-based model.

The toolbox produces three-dimensional plots and combinations of three-dimensional plots (depending on the number of parameters selected as inputs) to visualize the dependence of outputs on a selection of parameters. We choose to limit the study to three or four parameters for each set of simulations in order to generate plots that could be visually assessed. We run a number of simulations for different possible combinations of the parameters of interest; we show and discuss below a selection of most relevant results in terms of policy prescriptions.

In the surrogate model, the inputs are the parameters that the toolbox randomly draws in each repetition from the range that we specify. The outputs are the averages of the Gini indexes over the last 80 to 150 periods of each simulation (depending on

[20]The toolbox is available at the address `http://www.sumowiki.intec.ugent.be/Main_Page`.

the characteristics of each model and the outcomes of the single run simulations).[21]

6.1 Baseline model

Figure (13) plots the Gini index for wages for different tax rates on income and wealth, and three levels of the imitation parameter η: $0.3, 0.6, 0.9$. A higher taxation on income generates higher inequality in wages. A possible cause is the lower level of economic activity which increase unemployment and, through the mechanism in (26), slows down the dynamics of salaries and determines a larger dispersion across households. The Gini index is generally higher for bigger values of η with two exceptions: for roughly $0.35 \leq \tau_y \leq 0.45$ and $\tau_W < 1$ the Gini index is larger for $\eta = 0.6$, and for $\tau_y < 0.1$ and $\tau_W < 0.08$ inequality in wages is higher for $\eta = 0.3$.

Comparable results are shown in figure 14 for the Gini index for wages as dependent on the unemployment benefit and the minimum wage and different levels of the imitation parameter. In this case a larger minimum wage can decrease wage inequality while for large values of η an increase in the unemployment benefit can determine the opposite result. Single run simulations show that an increase in η can amplify fluctuations in aggregate demand, and as a consequence, trigger a mechanism similar to the one discussed in section 5.1: workers are subject to relatively wider idiosyncratic shocks in wages, which are expected to be larger the faster is the recovery of the economy, due to more generous transfers to unemployed workers.

Figure 15 shows that the combination of tax rate on income and level of the unemployment benefit that minimizes income inequality strictly depends on the degree of social imitation of the economy. In general, inequality is higher the stronger is social imitation. For low levels of social imitation, a level of taxation of $\tau_y \approx 0.4$ minimizes income inequality for low levels of the unemployment benefit, while a redistribution policy based on unemployment benefits must be accompanied by a low taxation rate to be effective. For higher degrees of social imitation, the gap between the actual propensities to save of low-wage earners and high-wage earners widens, determining an increase in wealth inequality (the relative plot is not shown here), with faster accumulation of debt for the former group and of wealth for the latter. As a consequence, an increase in the unemployment benefit appears to be ineffective whereas higher taxation rates can curb inequality when $\eta = 0.6$, although only to a limited extent.

6.2 Technological progress with constant functional distribution of income

Figure 16 reveals that, in the case of technological progress, inequality in wages is higher the larger is γ_1, which quantifies the responsiveness of the rate of technical change to increases in capacity utilization. An increase in the tax rate on income, and to a lesser extent of the tax rate on wealth, reduce the overall inequality and their differences for different levels of γ_1. The effect is larger for lower taxation rates while for τ_y approximately larger than 0.5 no change in the Gini index is clearly noticeable.

[21]The choice of the sub-period depends on the amplitude and frequency of the fluctuations for each value of the parameter and has the aim to isolate the effect of the parameter's changes.

The results for the Gini index for income (not shown) are similar although the variation due the different levels of γ_1 is less neat.

6.3 Technological unemployment and varying functional distribution of income

For this model we focus our attention on four parameters: the tax rate on income τ_y, the unemployment benefit b, the sensitivity of labor productivity growth to capacity utilization γ_1 and the sensitivity of the mark-up rate to unemployment γ_2. Both single run simulations and the analysis of the surrogate model show that τ_y and b are the most effective policy parameters. However, from figure 17 it is evident that the effectiveness of each policy mix depends on the structural parameters: the capacity of the firm sector to innovate as a response to increase in demand and the institutional characteristics of wage bargaining.

It is evident that an increase in γ_1 brings about a larger degree of inequality for any possible levels of the other parameters. A faster pace of technical progress creates more technological unemployment, increasing income inequality. In general a redistributive fiscal policy (higher taxes and larger transfers) has a noticeable effect; for $\gamma_1 = 0.5$ an increase in the tax rate appears to be more effective than a raise in the unemployment benefit. Changes in γ_2 have little influence, but in general inequality appears to be higher for larger values of the parameter, except for $\gamma_1 = 0.5$. Looking at the single run simulations, a larger γ_1 determines wider business fluctuations, and due to (36), larger volatility in the functional distribution to a degree dependent on γ_2. As a consequence, in a scenario with relatively high unemployment a lower γ_2 determines less dramatic swings in the cycle with a marginally positive effect on income inequality.

6.4 Technological unemployment, varying functional distribution of income, and zero tax on wages

Since in this last scenario unemployment is null for different combinations of the parameter, we focus our attention on the two tax rates in order to obtain policy prescriptions. Figure 18 plots the results for a different range of variation for γ_1 compared to figure 17 to limit the number of crashes (as the one shown in figure 9) that could generate spikes in the surfaces.

In contrast with the previous scenario with a positive tax on wages, in this model both γ_1 and γ_2 appear to have a more limited effect on total income inequality. The drop to zero of the Gini index in the right panel of figure 18 is due to repeated crashes occurring when both tax rates are set at the minimum.

A larger sensitivity of functional distribution to unemployment γ_2 determines higher inequality only when $\gamma_1 = 0.25$ and the tax rates are relatively high. However γ_2 strongly affects the outcomes of the different combinations of tax rates. Looking for example at the central panel of figure 18, a wealth tax rate in the range $0.1 - 0.15$ can substantially reduce inequality if $\gamma_2 = 0.25$ while it determines the opposite effect if $\gamma_2 = 0.125$. In general, in this scenario, the Gini index on income is more sensitive to the tax rate on wealth, possibly due to the fact that in a situation of full employment a larger proportion of workers can accumulate wealth and, as the tax rate on income is in fact a tax rate on profit, it hits all households more evenly. The tax rate on income has a more visible effect when $\gamma_1 = 0.25$ and the tax rate on wealth is low.

7 Concluding remarks

After the 2007-8 crisis, an emerging literature has studied the destabilizing features of a fall in the wage share, as observed in the United States since the 1980s, in a context of consumption-led growth fostered by household debt accumulation. The acknowledgment that this phenomenon has been accompanied in the US by an increase in inequality among wage earners, as highlighted in the findings by Piketty and Saez (2003) and Piketty (2014), is requiring an effort to incorporate the role of personal income inequality into these approaches. Indeed, as presented in Cynamon and Fazzari (2013), the upsurge in household debt in the 2000s can be largely explained by an increase in spending relative to income of the bottom 95% of the US income distribution.

This paper proposes a stock-flow consistent agent-based model for the investigation of the joint dynamics of functional and personal income distribution in the presence of demand-push innovation and technological unemployment. The model is composed of four sectors, namely firm sector, households, banking sector and the government. Firms make investment decisions independently, and obtain finance from retained earnings, as well as equity issuance. The household sector is composed by several heterogeneous and interacting agents who earn their income from two different sources: wages, which add up to a share of total output, and a share of profits. They also face interest payments on their stock of debt. Banks provide credit endogenously to workers, charging a constant interest rate, and the government collects taxes from household wealth and spend it in unemployment benefits.

The model is able to reproduce realistic outcomes in terms of income and wealth distribution. The joint exam of the evolution of the Gini indexes and the distributions of income and wealth during the business cycle sheds light on the shifts of agents within the distributions over the cycle that originate changes in the inequality index. The introduction of labor-saving technological progress has destabilizing effects, in particular if associated to modifications in the functional distribution of income. Without effective redistributive policies, the increase in unemployment eventually leads to a massive loss of purchasing power for wages and to the collapse of the economy. In such a situation, a flat tax rate on income does not appear to be an effective policy tool to stabilize the economy. In contrast, a different taxation scheme in which the tax rate on profit is larger than the taxation rate on wages (kept to 0 for simplicity in our analysis) is effective not only for stabilization but also enables the economy to reach full employment, albeit it does not totally eliminate the possibility of sudden and severe crises. Unemployment benefits also prove to be an effective tool to lessen the negative effects of rising unemployment and modifications in the functional distribution. However, the sensitivity analysis shows that the effectiveness of every policy measure is strongly dependent on behavioral and institutional parameters.

The model is parsimonious in order to focus on a limited number of factors and allow the identification of the causation effects within the system. Several extensions of this framework are possible. First, a more sophisticated treatment of fiscal and monetary policy could involve, respectively, a more sophisticated taxation system, and a Taylor-type rule to endogenize the policy rate. A second possible extension concerns the possibility for household of using credit also to buy shares during a stock-market boom.

This framework can be nicely integrated with Di Guilmi and Carvalho (2017) in order to have a full microfoundation of both the firms side and the households side. This extension would allow also for a more refined treatment of the innovation process, and its impact on firms' profitability and the market structure. From a methodological point of view, a more refined calibration on real data could enable the model to provide additional insight on the dynamics of inequality as a consequence of technological progress in real economies. Also, the numerical solution can be integrated by an analytical treatment along the lines of Chiarella and Di Guilmi (2011) and Di Guilmi and Carvalho (2017).

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Compliance with Ethical Standards

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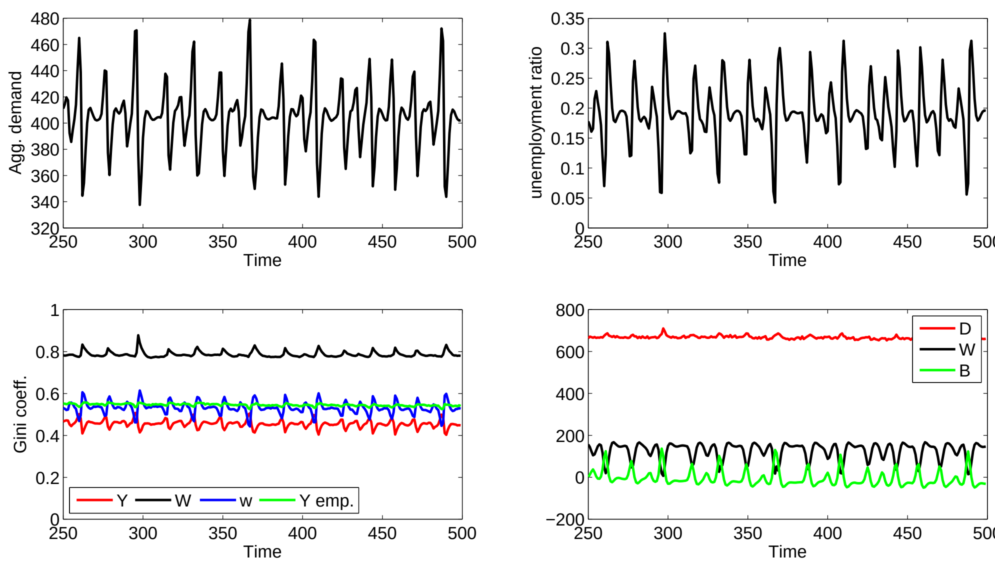

Figure 1: Aggregate demand (upper left panel), unemployment (upper right panel), Gini coefficients (bottom left panel), and real wealth, debt, and government wealth (bottom right panel) for a single run simulation of the baseline model.

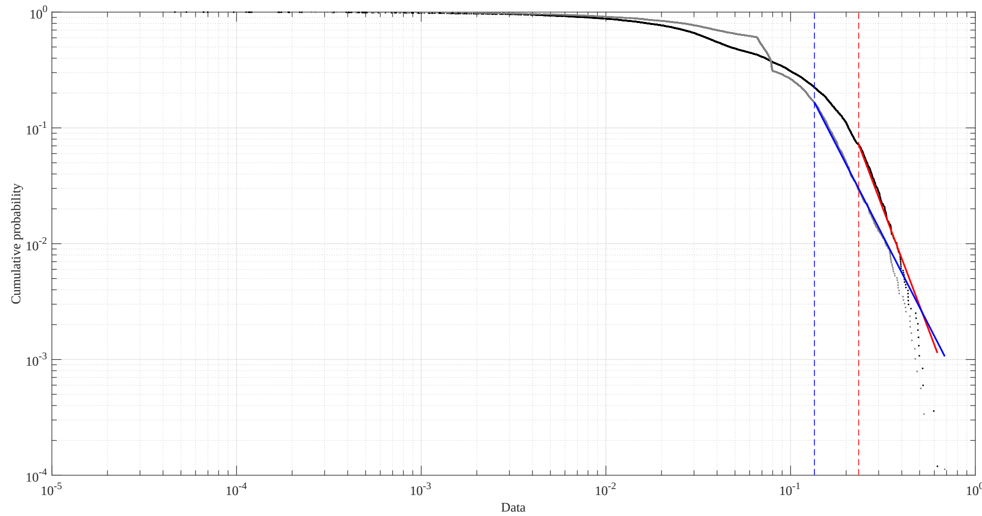

Figure 2: Cumulative distribution of income with Pareto fit at the peak (black points) and the trough (gray points) of the cycle.

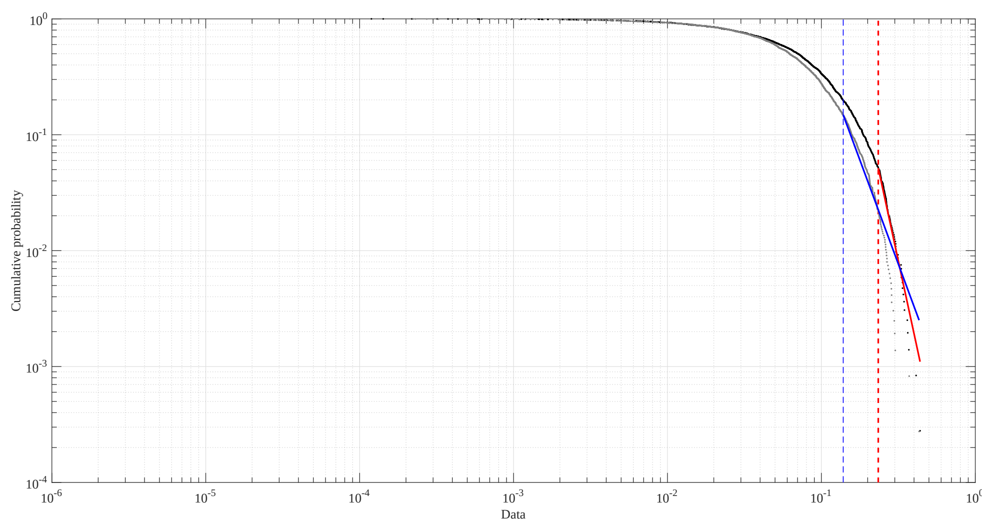

Figure 3: Cumulative distribution of wealth with Pareto fit at the peak (black points) and the trough (gray points) of the cycle.

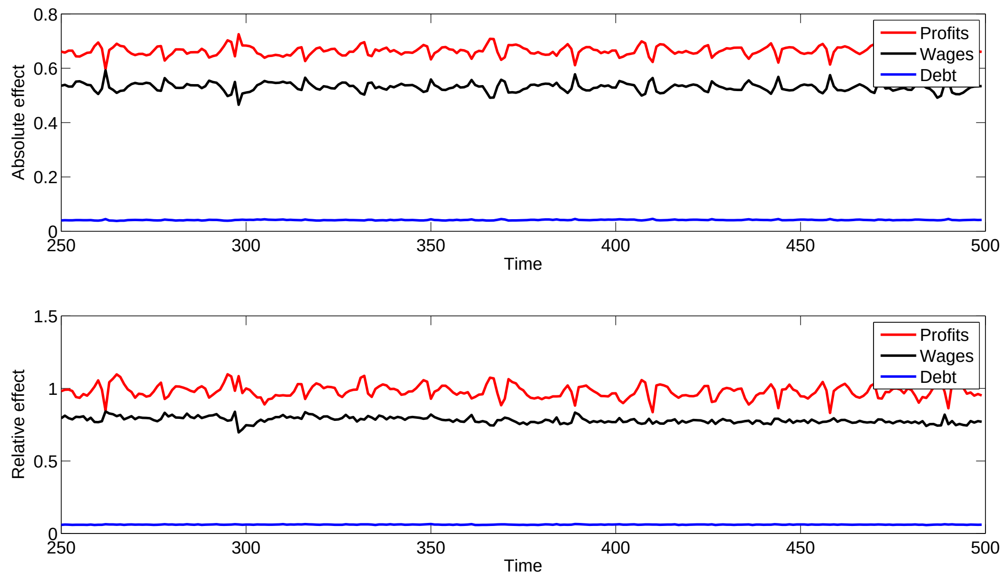

Figure 4: Factor decomposition for income dispersion. Single run simulation of the baseline model.

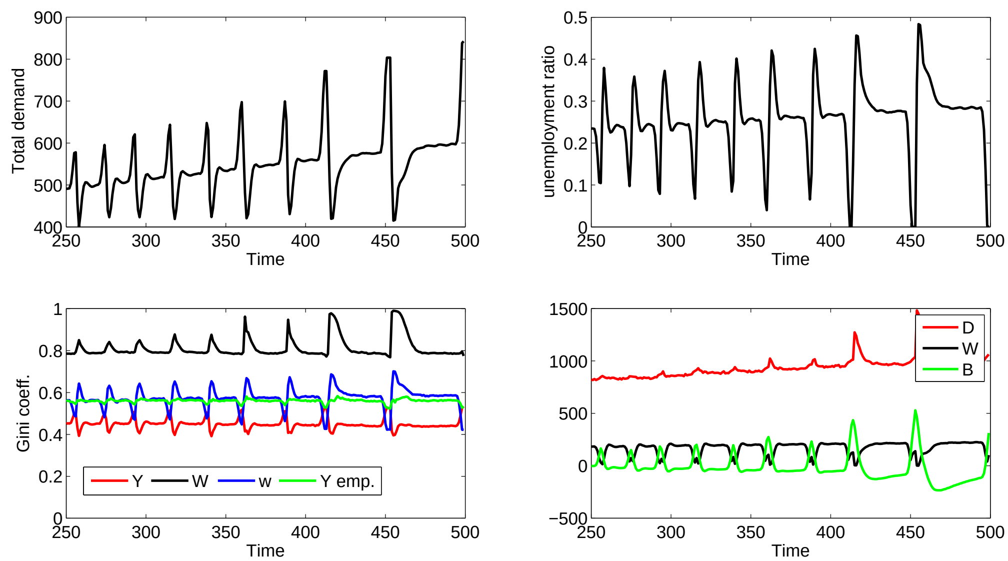

Figure 5: Aggregate demand (upper left panel), unemployment (upper right panel), Gini coefficients (bottom left panel), and real wealth, debt, and government wealth (bottom right panel) for a single run simulation of the model with technological progress.

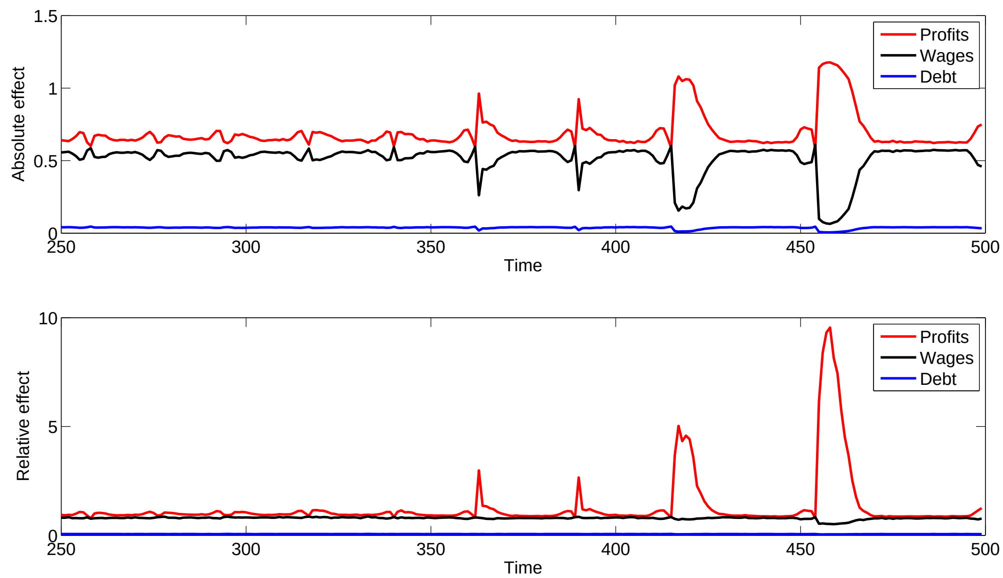

Figure 6: Factor decomposition for income dispersion. Single run simulation of the model with technological progress.

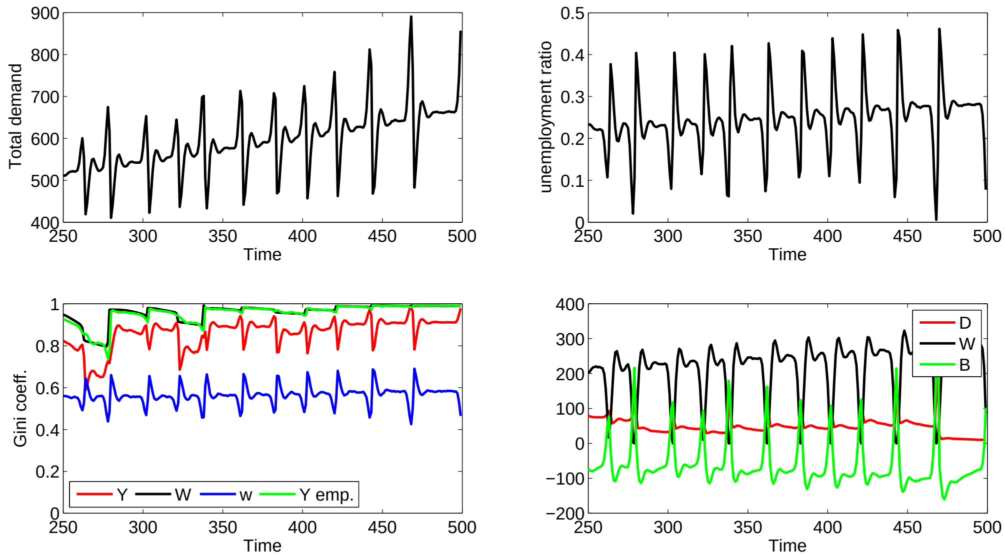

Figure 7: Aggregate demand (upper left panel), unemployment (upper right panel), Gini coefficients (bottom left panel), and real wealth, debt, and government wealth (bottom right panel) for a single run simulation of the model with technological progress and varying functional distribution.

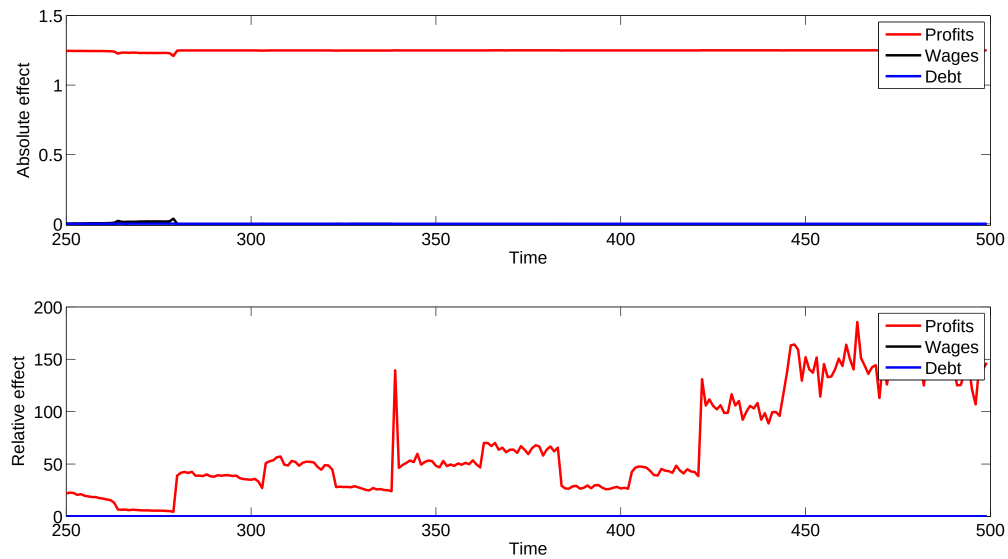

Figure 8: Factor decomposition for income dispersion. Single run simulation of the model with technological progress and varying functional distribution.

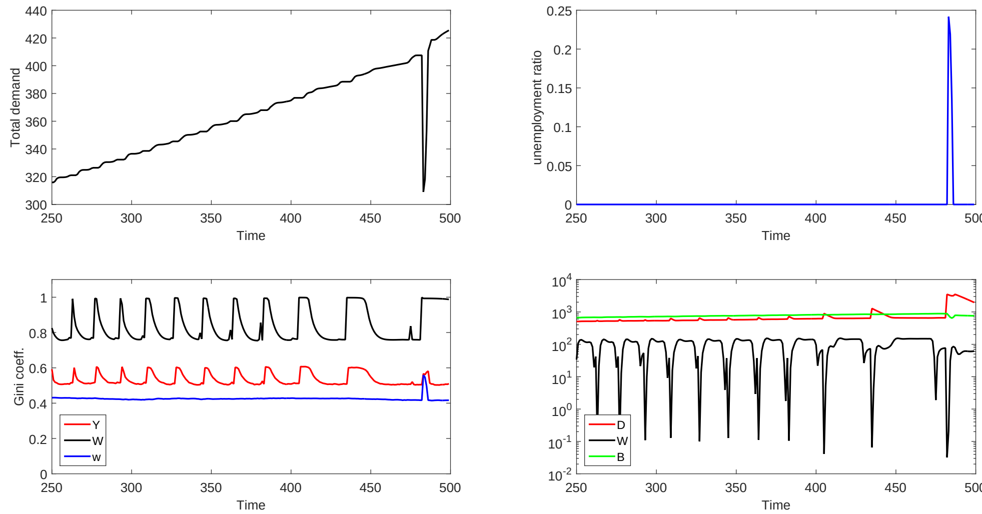

Figure 9: Aggregate demand (upper left panel), unemployment (upper right panel), Gini coefficients (bottom left panel), and real wealth, debt, and government wealth (bottom right panel) for a single run simulation of the model with technological progress, varying functional distribution, and no tax on wages.

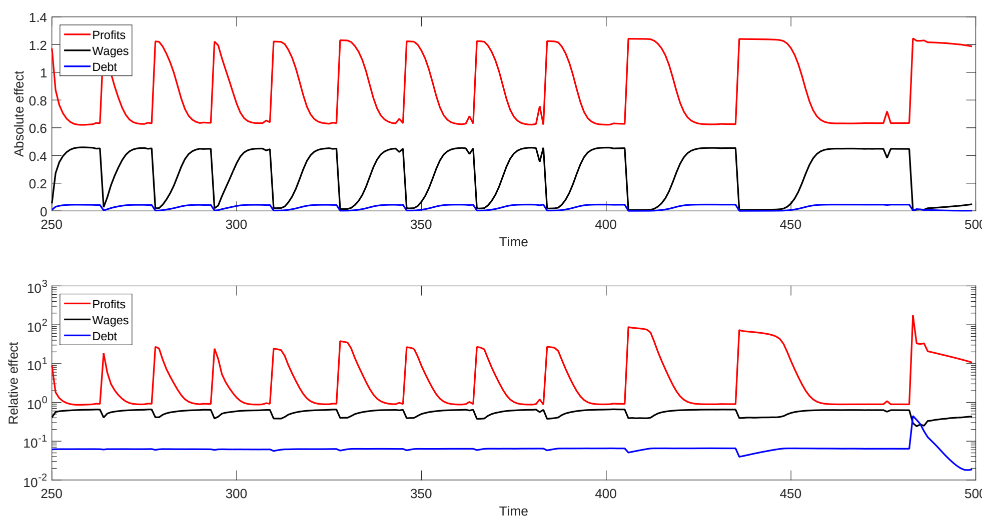

Figure 10: Factor decomposition for income dispersion. Single run simulation of the model with technological progress, varying functional distribution, and no tax on wages.

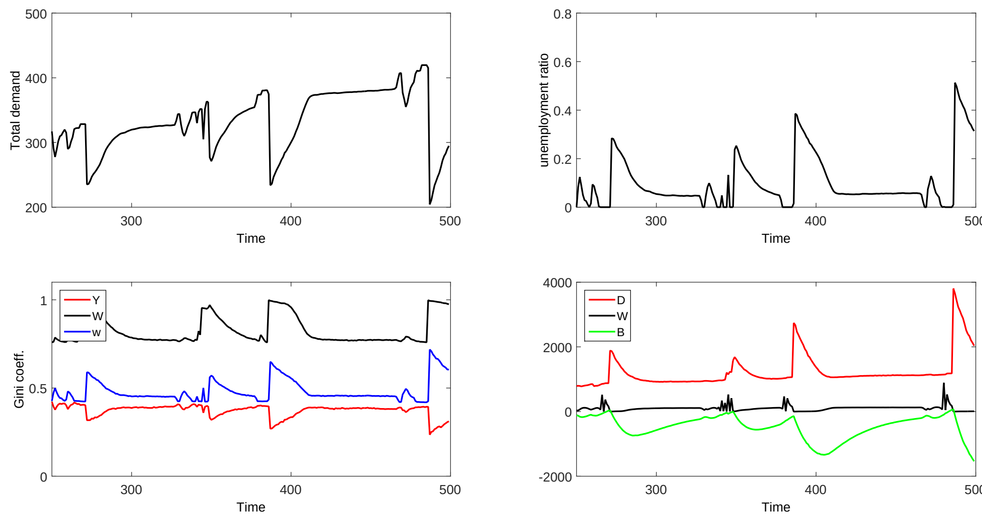

Figure 11: Aggregate demand (upper left panel), unemployment (upper right panel), Gini coefficients (bottom left panel), and real wealth, debt, and government wealth (bottom right panel) for a single run simulation of the model with technological progress, varying functional distribution, and $\tau_y = 0.05$.

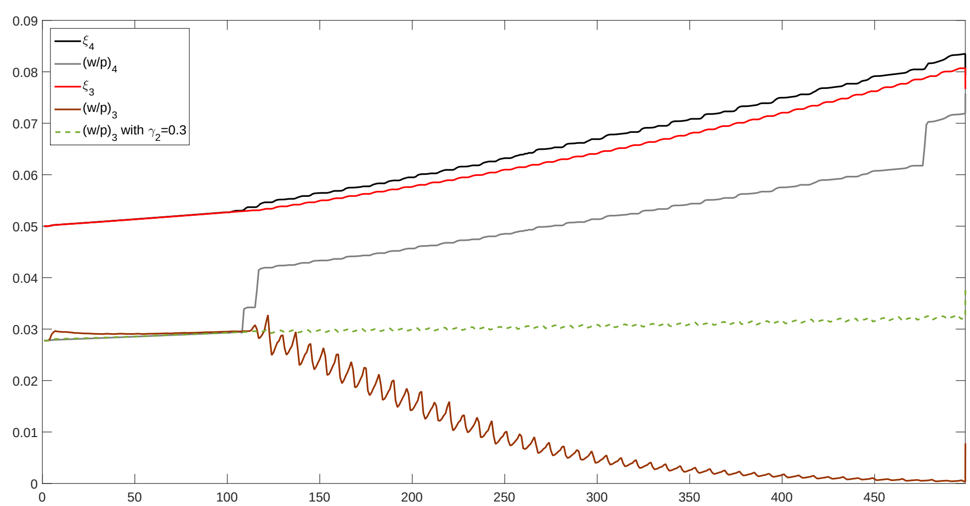

Figure 12: Productivity and real wage for the models with technological progress, varying functional distribution (indicated as 3), and no tax on wages (indicated as 4).

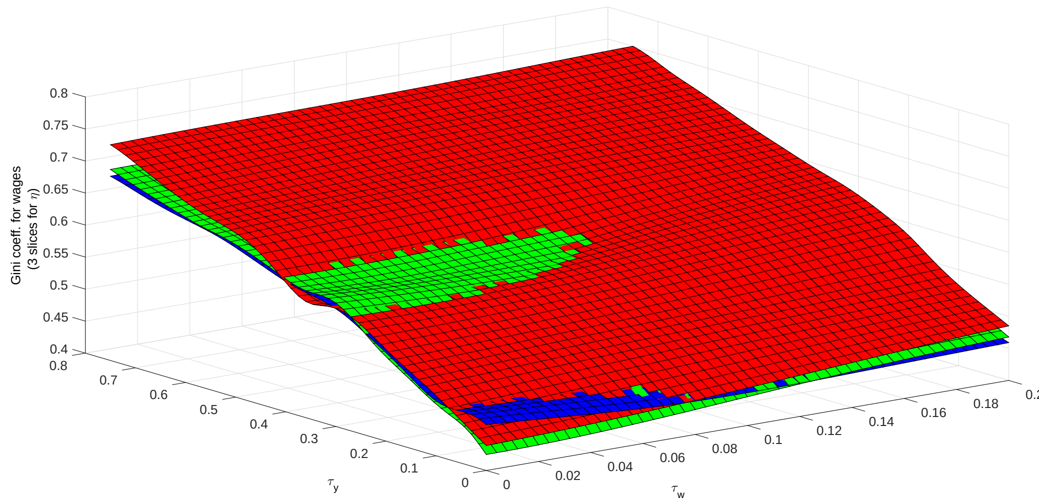

Figure 13: Analysis of the surrogate model. Gini coefficient for wages for different τ_y, τ_W, and $\eta = 0.3$ (blue surface) $\eta = 0.6$ (green surface), and $\eta = 0.9$ (red surface). Baseline model.

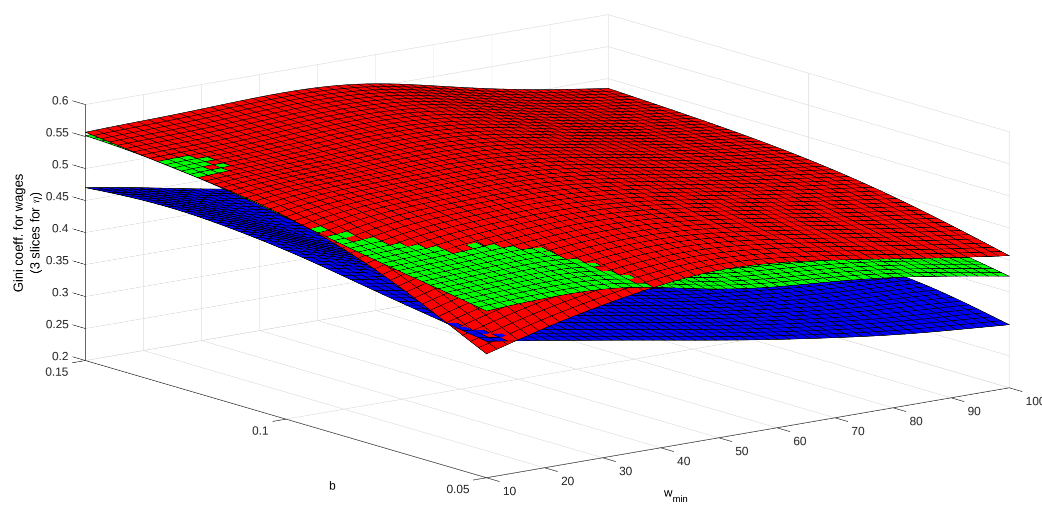

Figure 14: Analysis of the surrogate model. Gini coefficient for wages for different b, w_{min}, and $\eta = 0.3$ (blue surface) $\eta = 0.6$ (green surface), and $\eta = 0.9$ (red surface). Baseline model.

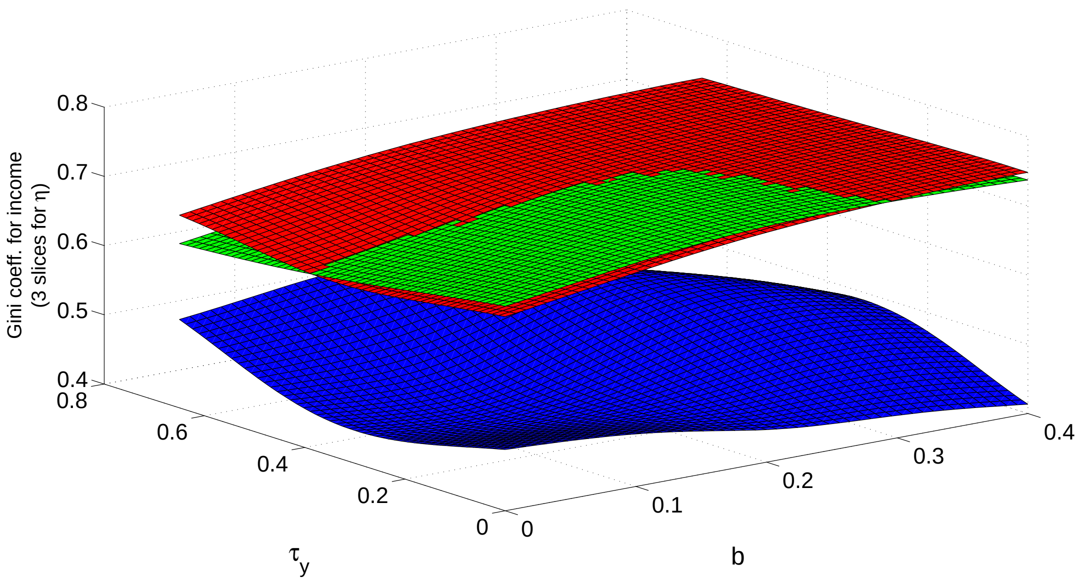

Figure 15: Analysis of the surrogate model. Gini coefficient for income for different b, τ_y, and $\eta = 0.3$ (blue surface) $\eta = 0.6$ (green surface), and $\eta = 0.9$ (red surface). Baseline model.

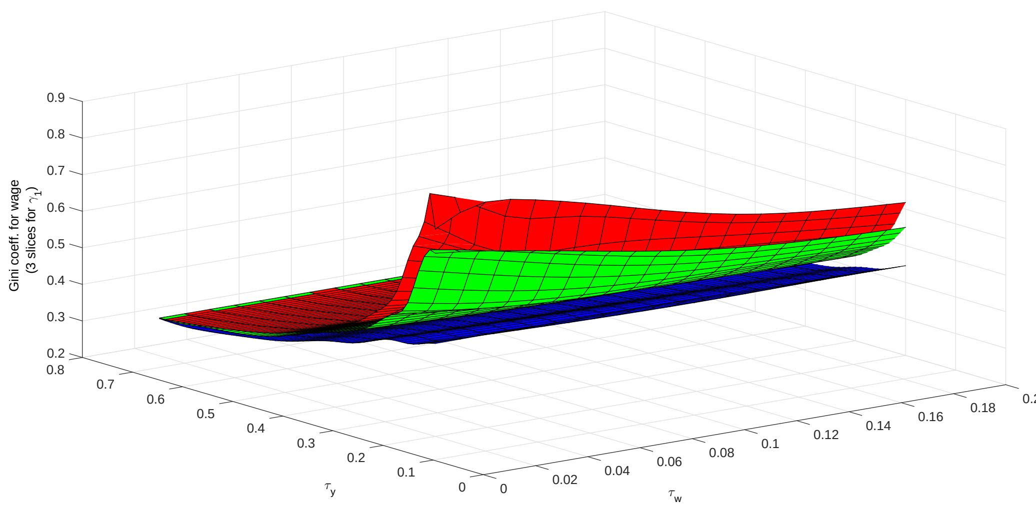

Figure 16: Analysis of the surrogate model. Gini coefficient for wages for different τ_y, τ_W, and $\gamma_1 = 0.01$ (blue surface) $\gamma_1 = 0.125$ (green surface), and $\gamma_1 = 0.25$ (red surface). Model with technological progress and constant functional distribution of income.

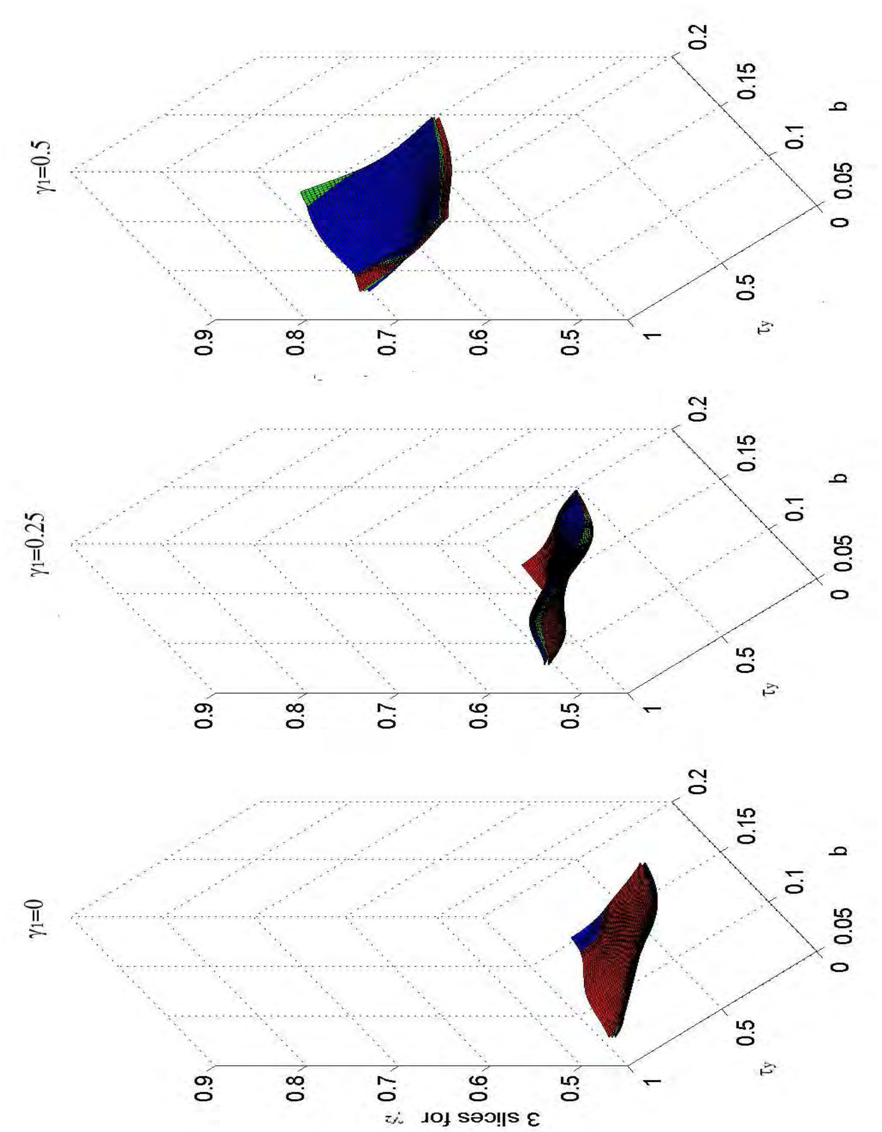

Figure 17: Analysis of the surrogate model. Gini coefficient for income for different τ_y, b, and $\gamma_1 = 0.01$ (blue surface) $\gamma_1 = 0.125$ (green surface), and $\gamma_1 = 0.25$ (red surface). Model with technological progress and varying functional distribution of income.

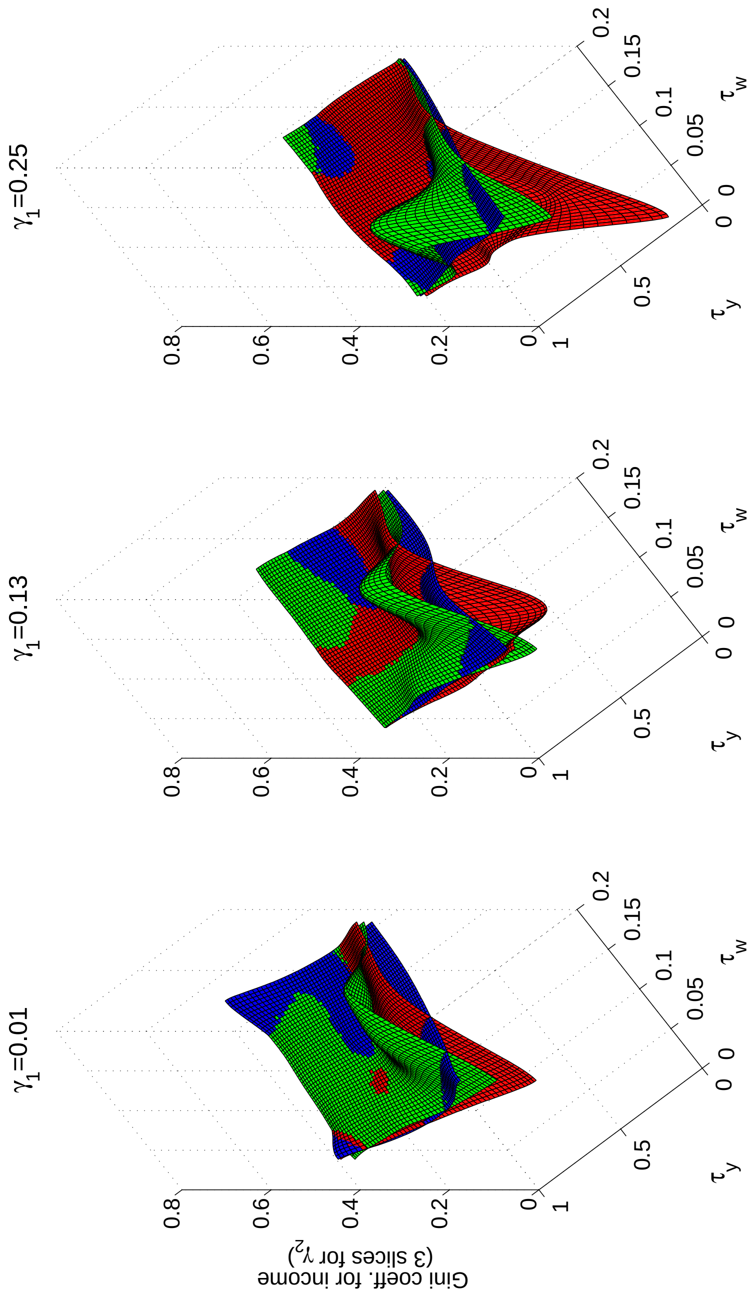

Figure 18: Analysis of the surrogate model. Gini coefficient for income for different τ_y, τ_W, and $\gamma_1 = 0.01$ (blue surface) $\gamma_1 = 0.125$ (green surface), and $\gamma_1 = 0.25$ (red surface). Model with technological progress, varying functional distribution of income, and zero tax on wages.