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The Costs of Meritocracy: An Agent-Based Model of Education, Inequality and Growth

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Abstract

The paper develops an agent-based model to study the complex interactions between access to education, inequality and economic growth. We simulate a "meritocratic" economy where households' ability to obtain (costly) education affects their future productivity and, in turn, their labor compensation. Simulation results show that in an economy characterized by unequal access to education and where workers are rewarded according to their productivity, income and wealth inequality surges, social mobility falls and economic growth is gradually eroded. This shows the emerging costs of meritocracy. Conversely, an institutional framework characterized by broad educational access and less meritocratic compensation schemes can foster higher and more inclusive growth. This can also be achieved introducing a policy which subsidizes education for households at the lower end of the wealth distribution. These results underscore the critical role of institutional arrangements and pre-distributive policies in promoting both equity and long-term economic performance.

Keywords: Income inequality, Education, Meritocracy, Social mobility, Pre-distribution, Economic growth, Agent-based computational economics.

JEL Codes: C63, D31, E21, I24

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1 Introduction

Economic inequality in income and wealth has become a defining and concerning feature of the global economic landscape in the twenty-first century (Piketty, 2014; Chancel et al., 2022). These widening gaps represent some of the most pressing social and economic challenges of our time, as extensive empirical evidence highlights their far-reaching consequences: constraining economic growth (Cingano, 2014; Berg et al., 2018), limiting social mobility (Corak, 2013; Chetty et al., 2014; Güell et al., 2018), and fueling unsustainable levels of debt (Rajan, 2010; Stiglitz, 2012; Cynamon and Fazzari, 2015).

Alongside the rise in inequality, education has emerged as an increasingly important determinant of economic success (Stiglitz, 2012, 2015; Goldin and Katz, 2018; Chetty et al., 2020). Yet at the same time, in the presence of surging education costs, pre-existing wealth increasingly determines education access, creating what some have called the *meritocracy trap* (Markovits, 2019; Sandel, 2020). Given the profound implications of economic inequality for both individual livelihoods and the broader macroeconomy, understanding its underlying drivers and the specific mechanisms is essential for designing effective policy responses.

Agent-based models (Dawid and Delli Gatti, 2018; Dosi and Roventini, 2019, 2025; Axtell and Farmer, 2025) are particularly well suited to study complex phenomena such as economic inequality, as they explicitly account for heterogeneity and allow aggregate outcomes to emerge from non-trivial microeconomic path-dependent interactions. Previous agent-based models have explored various aspects of economic inequality such as its link to innovation-driven growth (Dosi et al., 2010, 2013; Caiani et al., 2019), trade competitiveness (Fanti et al., 2024), policy effectiveness (Dosi et al., 2013, 2015; Fierro et al., 2023) and financial instability (Russo et al., 2016; Dosi et al., 2017; Russo, 2017; Cardaci, 2018; Cardaci and Saraceno, 2019; Botta et al., 2021). Comparatively few agent-based models explicitly incorporate education or human capital as drivers of macroeconomic and distributional dynamics (few exceptions include Fierro et al., 2022; Fanti et al., 2024; Jammeh et al., 2026). A key challenge remains in understanding how access to education affects economic disparities and macroeconomic outcomes across generations. This is precisely the focus of this work, which develops an agent-based model that explicitly links inequality, education, and wealth to examine the economic challenges posed by meritocracy-driven inequality.

Our agent-based model is inspired by Palagi et al. (2023) and features an economy composed by a good and a labor market where heterogeneous firms and households interact locally. Households are organized in dynasties: each household can invest in education only in the first five period of its work life, and it retires after forty periods, passing on any wealth to the next generation. A household can increase its labor productivity by accessing education by paying the associated cost. This also improves its income prospect, as firms reward their employees with a performance-based bonus tied to their individual labor productivity on top of the homogeneous wage. In such a meritocratic system, financially-constrained households in the bottom part of the wealth distribution may lack the resources to pay for education, thus losing future income opportunities.

We calibrate the model to the U.S. economy and perform extensive Monte Carlo simulation analyses. The results show that our model is able to replicate a broad set of stylized facts related to macroeconomic and distributional patterns of economic inequality and social mobility, such as increasing personal income and wealth concentration (Alvaredo et al., 2018; Piketty et al., 2018), high income immobility at the top (OECD, 2018; Barone and Mocetti, 2021) and the loss of educational opportunities by the middle class (Markovits, 2019). We find that unequal access to education significantly contributes not only to personal inequality but also to adverse macroeconomic outcomes (in line with OECD, 2015; Berg and Ostry, 2017; Berg et al., 2018). As educational disparities contribute to rising personal inequality, this dampens overall economic growth by limiting the overall productivity gains that could be achieved with more equitable educational access. This represents a structural limitation on the *supply side* of the economy. Furthermore, a productivity slowdown translates into weaker income growth for large parts of the population, which in turn limits the expansion of consumption and *aggregate demand*. Finally, the unequal access to education also restricts intergenerational mobility, thereby perpetuating economic inequality across generations. This feedback loop between inequality, education, and macroeconomic performance shows how the emergence of a *meritocracy trap* can gradually erode both long-term growth and social cohesion.

To further investigate these dynamics, we run several simulation scenarios varying both the firms' bonus payout structure and the cost of education. We identify four distinct regimes. When bonuses are highly skewed toward top performer workers and education is expensive, economic inequality is high and growth is sluggish due to limited access to education and weak aggregate demand. Lowering education cost growth in this setting increases access to education but does not fully counterbalance the negative effects of inequality, as high income concentration still hampers households' consumption and, hence, broader economic activity. Conversely, when bonuses are distributed more evenly but education remains costly, inequality is reduced, but economic growth remains weak due to constrained productivity growth. The most favorable regime, with low inequality and high growth, arises when both firms' rewards are more equitably distributed and education costs are low. This fosters a more inclusive economy with broad access to education, reduced inequality, and robust economic expansion. These findings further shed light on the costs of meritocracy when access to education is costly and uneven: while it rewards individual effort and productivity, it exacerbates inequality and undermines overall economic activity, In this context, a less meritocratic labor compensation scheme can reduce inequality without compromising macroeconomic performance

Finally, we design a policy experiment wherein the government subsidizes education for households at the bottom of the wealth distribution which otherwise are not be able to access education. We find that such targeted educational interventions can simultaneously lead to higher economic growth and larger income shares for lower-income groups without increasing the long-run fiscal burden. More broadly, our simulation results point two complementary avenues toward more inclusive growth: pre-distributive policies (Blanchet et al., 2022; Bozio et al., 2024) that broaden access to education, and institutional arrangements that limit excessive inequality in labor remuneration.

The rest of the paper is organized as follows. Section 2 presents recent trends in educational and economic inequality and discusses the related literature. Section 3 describes the model. Section 4 presents the results of our simulations, and Section 5 concludes.

2 Trends in economic and educational inequality

Economic and educational inequality have been rising in many countries over the past decades, with significant implications for economic mobility, labor market outcomes, and long-term economic growth. While much of the empirical literature focuses on documenting these trends, less attention has been given to their systemic interactions and macroeconomic consequences. This section presents key indicators and stylized facts of economic and educational inequality in the United States and highlights the reinforcing interaction between them: rising income concentration increasingly shapes access to education, while educational attainment increasingly determines access to top incomes.

Figure 1 presents an overview of key indicators of economic inequality in the United States. These include a decline in the labor share in GDP (Figure 1a), rising Gini coefficients for income and wealth (Figure 1b), and an increasing concentration of national income among the top 10% of earners (Figure 1c). Notably, even as the overall labor share is declining, an increasingly larger portion of it is being captured by the highest income groups. Recent evidence suggests a significant transformation in the composition of top incomes, with labor income, including wage income and bonuses from business profits, playing an increasingly important role (Markovits, 2019; Berman and Milanovic, 2024), even as inherited wealth and capital income continue to be central components of top-tier wealth accumulation[1]. Consistent with this trend, the share of "self-made" individuals[2] within the Forbes 400 increased substantially from less than half in 1984 to 70% in 2023 (Forbes, 2024). The growing labor-income polarization is reflected also in other inequality statistics such as the CEO-to-worker compensation ratio (Figure 1d). These trends in economic inequality underline the importance of understanding how structural factors, including access to education, influence economic inequality.

The rise in economic inequality has been widely discussed, with several key factors identified as drivers of this trend. Among these are globalization (Feenstra and Hanson, 1996), skill-biased technological change (Acemoglu, 2002; Autor et al., 2008), declining top marginal tax rates (Roine et al., 2009), technological advancements such as automation (Autor, 2015), changes in labor market institutions like the weakening of unions and the stagnation of minimum wages (Dosi et al., 2018, 2021; Jaumotte and Osorio Buitron, 2020; Mishel and Bivens, 2021), and financial deregulation (Roine et al., 2009; Jaumotte and Osorio Buitron, 2020). Additionally, access to education remains a critical determinant of economic mobility and income distribution

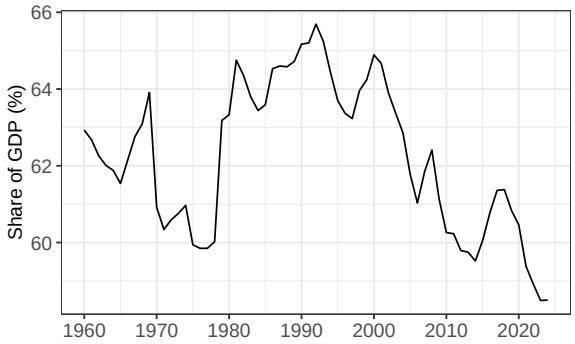
[1]Note that the frontier between labor and capital income flows may be fuzzy and dependent on tax advantages (Piketty et al., 2023). While this issue is not addressed in this paper, it represents a promising direction for future research. Moreover, it is important to recognize that also other countries—such as Italy—have experienced rising inheritance flows, which have contributed to growing wealth inequality (Acciari et al., 2024). Furthermore, also in the U.S. inheritance flows are growing faster than aggregate income (Morelli et al., 2025).

[2]Since 2014, Forbes has included a "self-made score" for each member, ranging from 1 (primarily inherited wealth) to 10 (entirely self-made wealth).

(Stiglitz, 2012). As the importance of labor income for the richest part of the population has been growing over time, so has the significance of educational attainment in determining individuals' economic prospects.

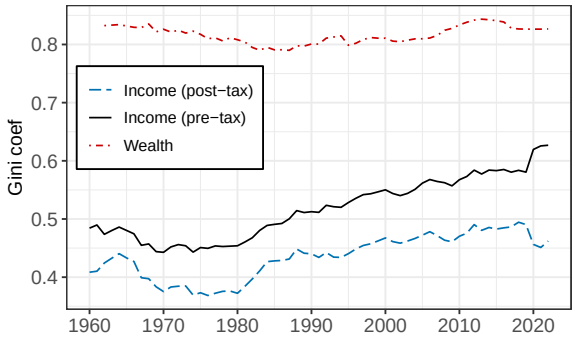
Figure 1: Key indicators of economic inequality in the United States

(a) Labor share



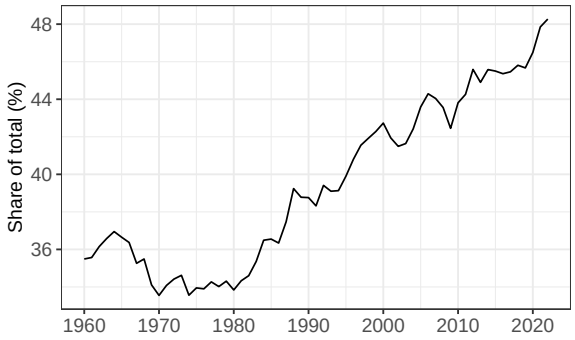
Data source: World Inequality Database (Alvaredo et al., 2018)

(b) Gini indices



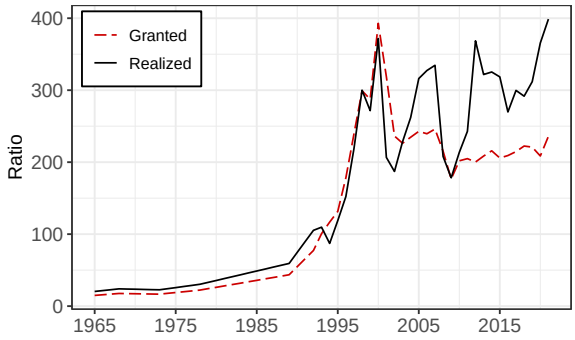
Data source: World Inequality Database (Alvaredo et al., 2018)

(c) Top 10% national income share



Data source: World Inequality Database (Alvaredo et al., 2018)

(d) CEO-worker compensation ratio

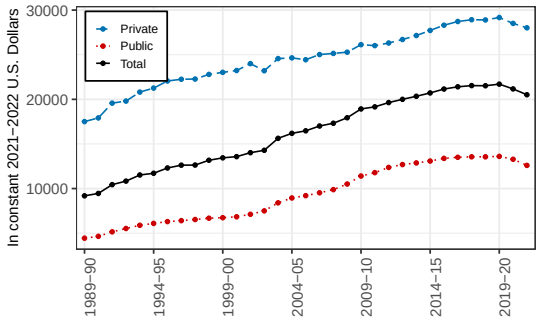


Data source: Economic Policy Institute (Bivens and Kandra, 2022)

While education has traditionally been viewed as a channel of upward mobility, increasing disparities in access to education risk transforming it into a mechanism for reproducing existing socioeconomic advantages. When access to education is unequal, meritocracy, often seen as a system of fairness and equal opportunity, becomes deeply problematic. Those with pre-existing advantages are better positioned to secure the best educational resources, further entrenching their socioeconomic status. As Michael Young warned in 1958, such a system risks greater social stratification, where a new elite class justifies its privilege as a product of "merit". Contemporary scholars like Markovits (2019) and Sandel (2020) argue that meritocracy, far from leveling the playing field, legitimizes and actually enforces the concentration of wealth and power—a phenomenon known as the *meritocracy trap*. In this dynamic, the wealthy can disproportionately pay for education and acquire exceptional skills, thereby securing the best educational opportunities and highest-paying jobs for themselves. This results in a cycle where economic success is increasingly tied to pre-existing wealth, thereby perpetuating and deepening existing economic disparities.

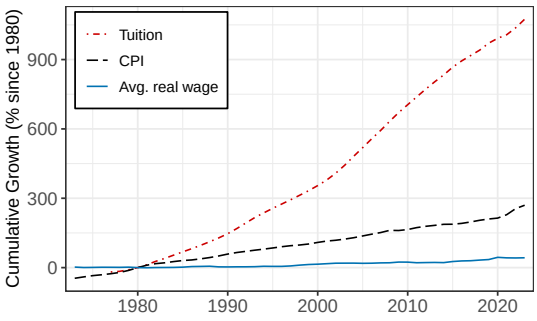
Figure 2: Key indicators of educational inequality in the United States

(a) Average cost of college education



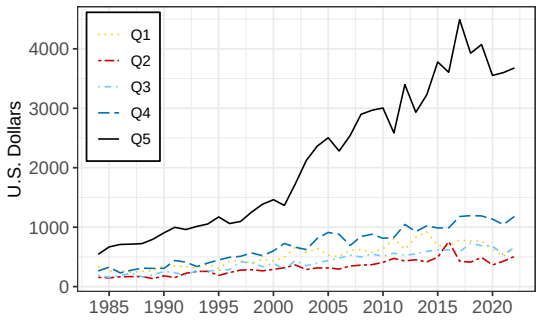
Data source: U.S. Department of Education, National Center for Education Statistics (2023)

(b) Real wages, inflation, and tuition costs



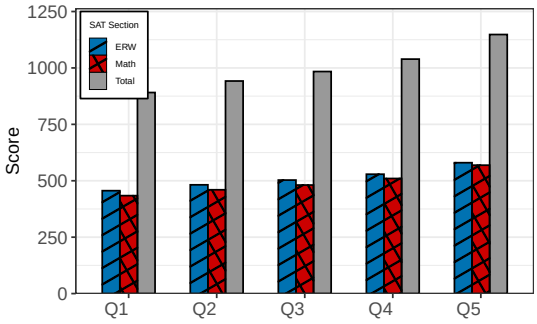
Data sources: Real wages from Economic Policy Institute (2024); CPI and tuition from U.S. Bureau of Labor Statistics (2025a) and (2025b).

(c) Education expenditures by income quintiles



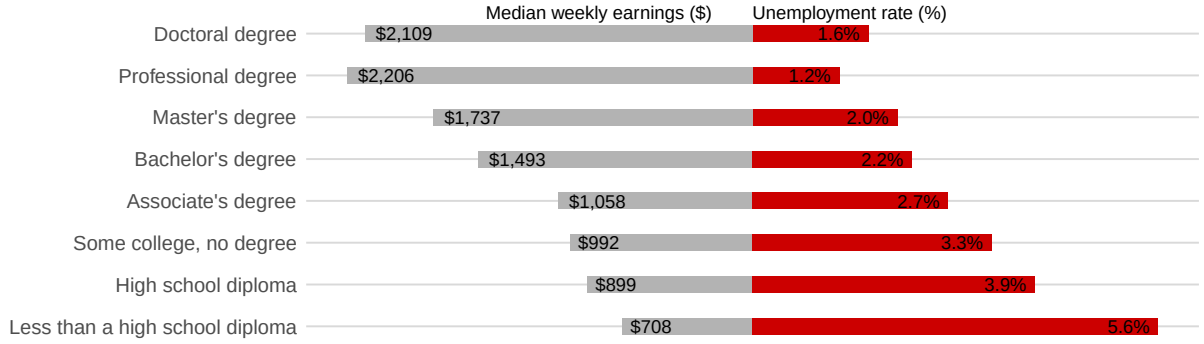
Data source: U.S. Bureau of Labor Statistics, Consumer Expenditure Survey (2024a)

(d) SAT scores by income quintiles, 2023



Data source: 2023 SAT Suite Annual Report (College Board, 2023)

(e) Earnings and unemployment rates by education, 2023



Data source: U.S. Bureau of Labor Statistics, Current Population Survey (2024b)

Existing empirical evidence supports the claim that access to education has become increasingly competitive, costly, and unequal. Figure 2 presents key indicators highlighting such trends. These include a significant rise in tuition costs at post-secondary institutions (Figure 2a), a major driver of growing educational inequality, as extensively documented by Stiglitz (2012) or Goldin and Katz (2018). Since 1980, tuition costs have surged over 13-fold, vastly outpacing both inflation and modest real wage growth—highlighting the increasing financial burden of higher education, especially for the less well-off (Figure 2b). Spending on education

by income quintile shows that wealthier families invest substantially more in their children's education (Figure 2c). Academic performance, measured by SAT scores, is strongly correlated with family income (Figure 2d), which contributes to persistent disparities in access to selective institutions (Putnam, 2016; Chetty et al., 2017, 2020). Finally, differences in earnings and unemployment rates by educational attainment highlight the persistent labor market advantages of higher education (Figure 2e), consistent with long-standing evidence of substantial returns to college (Card, 1999; Oreopoulos and Petronijevic, 2013; Mountjoy, 2025).

These trends collectively underscore the critical role of education in shaping economic inequality and mobility. Rising tuition costs, unequal spending on education, and disparities in academic performance highlight how access to education is increasingly determined by socioeconomic status. As a result, unequal access to education not only reflects but also perpetuates existing inequalities, reinforcing barriers to social mobility and economic opportunity.

A large empirical literature has examined the relationship between inequality and economic growth, with many studies finding that high levels of inequality are associated with weaker growth. In particular, cross-country evidence suggests that greater income inequality tends to reduce subsequent economic growth, especially when inequality is concentrated at the lower end of the income distribution (Cingano, 2014; Voitchovsky, 2005). Moreover, Berg and Ostry (2017) and Berg et al. (2018) show that excessive inequality shortens the duration of sustained growth spells and reduces long-run growth stability.

One important channel through which inequality can affect growth is human capital accumulation. When access to education depends heavily on household income and wealth, high inequality can limit educational investment among lower-income groups, reducing aggregate human capital formation and long-run productivity growth (Stiglitz, 2012). Empirical evidence supports this link. Higher levels of inequality are associated with lower intergenerational mobility and greater persistence of educational and income inequalities across generations (Corak, 2013; OECD, 2015; Chetty et al., 2020). From this perspective, educational inequality does not merely reflect existing economic disparities, but also functions as a transmission mechanism through which economic inequality persists over time and affects long-run macroeconomic performance.

At the theoretical level, the relationship between inequality, education, and growth has been studied in neoclassical models of human capital accumulation and intergenerational transmission. A major contribution is Galor and Zeira (1993), where borrowing constraints and fixed educational costs generate persistent inequality and affect long-run growth through human capital accumulation. Related contributions also emphasize parental investment, socioeconomic segregation, and early childhood education as key channels linking inequality to economic growth (Becker and Tomes, 1986; Benabou, 1994; Caucutt and Lochner, 2020). This literature, however, typically studies education within stylized dynastic, equilibrium-based frameworks in which educational decisions are modeled primarily as representative individual or family optimization problems, with intergenerational outcomes shaped by parental altruism—captured, for example, through dynastic-specific rates of time preference—and forward-looking behavior. Macroeconomic outcomes then emerge from the aggregation of optimizing decisions under rel-

atively strong assumptions about expectations, coordination, and market adjustment, leaving more limited scope for richer social interactions, adaptive behavior, and endogenous feedback dynamics. As a result, these frameworks are less suited to capturing how educational inequality, labor-market stratification, and macroeconomic outcomes jointly evolve through heterogeneous interactions, cumulative advantage, and path-dependent processes. In particular, they do not explicitly model self-reinforcing dynamics through which unequal educational opportunities may reproduce elite status and income concentration over time, as emphasized by the notion of the *meritocracy trap*.

These limitations motivate the use of agent-based models (ABMs), which explicitly represent heterogeneous, interacting individuals over time and are therefore well suited to studying the co-evolution of educational inequality, intergenerational mobility, and macroeconomic dynamics as emergent outcomes of decentralized interaction rather than equilibrium adjustment (Dosi and Roventini, 2019, 2025; Durlauf et al., 2025). Rising inequality and its macroeconomic consequences have been studied extensively in the agent-based literature.

A first strand focuses on the interaction between firm dynamics, income distribution, and growth, showing how labor-market institutions, innovation, and functional income distribution shape inequality, unemployment, business cycles, and long-run growth (Dosi et al., 2010, 2013, 2017, 2018, 2021; Caiani et al., 2019).[3] Related contributions analyze the role of fiscal policies, such as progressive taxation and redistribution, in mitigating inequality and promoting macroeconomic stability (Palagi et al., 2017, 2023). Extending this line of research, this paper centers on households and evaluates the importance of policies targeting meritocracy-driven inequality, with a particular focus on access to education and its influence on income distribution and economic performance.

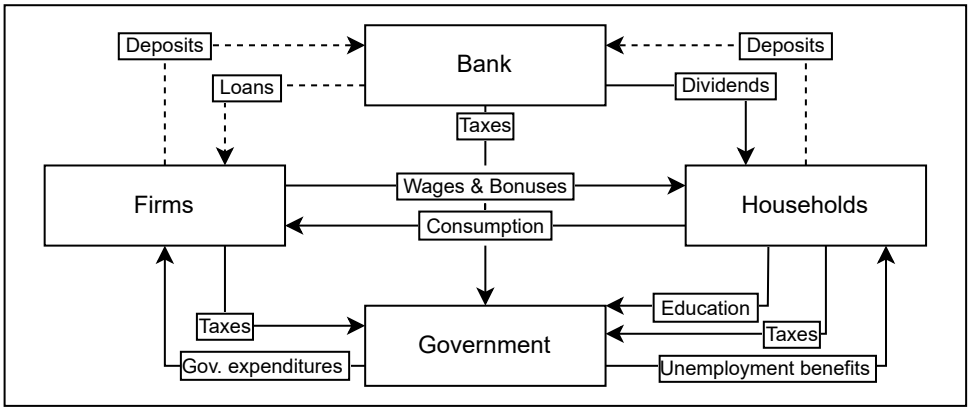
A second and relatively recent strand of agent-based models explicitly incorporate educational inequality as a driver of macroeconomic and distributional outcomes. Fierro et al. (2022) study the macroeconomic effects of automation and skill formation in a multi-sector model, while Fanti et al. (2024) analyze how cross-country educational disparities affect growth trajectories and trade competitiveness. Most recently, Jammeh et al. (2026) examine how inheritance taxation and redistribution influence long-run wealth inequality through human-capital accumulation in an agent-based overlapping-generations framework focused on household dynamics. Our paper adds to this strand by studying the endogenous co-evolution of *within-country* educational inequality, intergenerational mobility, and macroeconomic performance. Our framework places particular emphasis on the endogenous emergence of educational inequality through the interaction between household resources, merit-based labor-market rewards, and macroeconomic dynamics. The model thereby generates important feedback mechanisms linking inequality of opportunity, inequality of outcomes, and long-run growth.

[3]Several studies also investigate the relationship between inequality and financial fragility, highlighting how rising inequality can amplify leverage cycles and macroeconomic instability (Russo et al., 2016; Russo, 2017; Cardaci, 2018; Cardaci and Saraceno, 2019; Botta et al., 2021).

3 The model

The model is inspired by Palagi et al. (2023) and features an economy consisting of N dynasties of households, F firms, a commercial bank and a government. Firms produce a consumption good by employing a linear technology that requires only labor. Households supply labor inelastically and consume the final good using their current income and previously accumulated wealth. Eligible households with sufficient financial resources can invest in education which raises, on average, their labor productivity. Firms pay a within-firm homogeneous wage to all their employees plus a performance-based bonus tied to each employee's individual labor productivity. The economy thus embeds a *meritocratic institutional arrangement* as education leads to higher individual productivity which is rewarded with higher labor compensations. Finally, the government buys a small share of production, provides educational services, pays unemployment benefits and collects taxes. Figure 3 shows the model structure and interactions between the agents of our simulated economy.

Figure 3: Flow diagram of the model



Notes: Arrows point from the paying to the receiving sector. Dashed lines imply interest payments in the arrow's opposite direction.

As is typical in the agent-based literature, we assume that both firms and households rely on simple adaptive rules and heuristics in their decision-making,[4] in line with ample empirical evidence (Gigerenzer and Brighton, 2009; Gigerenzer and Goldstein, 2011; Hommes, 2013). Heterogeneous firms and households interact locally in the labor and the goods markets following a common matching protocol in the spirit of Guerini et al. (2018) and Ciambezi et al. (2025). Moreover, the model is stock-flow consistent at both the micro and macro levels: every transaction has a corresponding counterpart, and all flows are consistently recorded in agents' balance sheets and aggregate accounting identities.(Godley and Lavoie, 2007).

Let us now describe the sequence of events taking place in each time period. We then detail the behavioral rules governing our agents' actions and interactions.

[4]For more general information on the agent-based modeling methodology and its application in macroeconomics we refer to Fagiolo and Roventini (2017), Dawid and Delli Gatti (2018), Dosi and Roventini (2019, 2025) and Cincotti et al. (2022).

3.1 Sequence of events

The model is run for T periods. Each period corresponds to a year. During every period t, a series of events unfolds as follows:

1. *Educational expenditures and technological progress*: eligible households with sufficient resources invest in education.
2. *Production planning:* firms decide their wage offer, desired production, credit and labor demand.
3. *Credit extension:* the commercial bank extends loans to firms.
4. *Labor market interactions:* firms with vacancies interact with unemployed households in the labor market.
5. *Production:* once the labor market closes, the production of consumption goods takes place and their prices are set.
6. *Wages and unemployment benefits:* employed households receive wages while unemployed households receive unemployment benefits from the government.
7. *Consumption planning:* households determine their desired consumption based on their current income and previously accumulated wealth.
8. *Goods market interaction:* the government, households and firms interact in the goods market.
9. *Debt service and default:* firms pay any loans they have plus the owed interest. If a firm fails to service its debt, it defaults and the bank incurs a non-performing loan.
10. *Bonus and dividend payments:* firms compute their profits and pay out performance-based bonuses to their employees, while the bank pays out a share of its profits to households as dividends.

At the end of each period, households that have reached the end of their work life retire and transfer any wealth they have to the next generation in their dynasty. Aggregate variables related to the household and firm sector are calculated by summing up the corresponding individual ones.

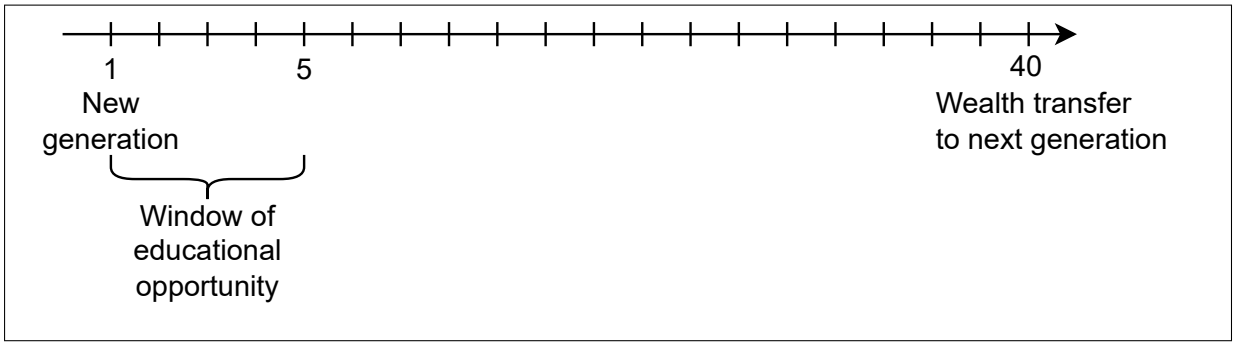
3.2 Households

Work life. Households' work life is set to 40 periods, approximating the latest expected average working life duration in the European Union[5], which was 36.5 years in 2022 (Eurostat, 2022). Figure 4 depict the work life of a typical household, who work, consume and obtain education.

[5]The U.S. Bureau of Labor Statistics (2024c) has not published any worklife estimates for the United States since 1986.

Note that while households work and consume in every period of their work life, they can obtain education only in the first five periods, as formal education is typically completed in the early stages of an individual's career. We call this initial period the "window of educational opportunity". At the end of their working lives, households retire and bequeath their accumulated wealth to the next generation in their dynasty.

Figure 4: Representation of a household's work life



Education and technological progress. Educational attainment determines households' labor productivity ($A_{n,t}$), in line with the literature linking human capital accumulation to productivity growth (e.g., Bharti et al., 2026). As previously mentioned, non-educated households whose work life in period t is less or equal to five are *eligible* for obtaining education.

The cost of accessing education is equal to:

$$EC_t = EC_{t-1}(1 + \phi_{EC} \cdot g_{\bar{W},t}), \quad \phi_{EC} \in \mathbb{R}^+. \tag{1}$$

where $(g_{\bar{W},t})$ is the average growth of wages in the current period and ϕ_{EC} is a parameter relating the cost of education to the evolution of wages. When ϕ_{EC} is greater than 1, the cost of education increases in every period at a rate exceeding the average wage growth. This assumption is supported by empirical evidence showing (i) that the cost of education and wage dynamics are related (Archibald and Feldman, 2008), and (ii) that the cost of education in the United States across both public and private institutions has consistently risen over time, often outpacing inflation and wage growth (Goldin and Katz, 2018; Ma and Pender, 2023). The cost of education (EC_t) is incurred only if an eligible household has the necessary resources (i.e., inherited or previously accumulated wealth) to pay for education. A household's education status is represented by the binary indicator $E_{n,t}$, meaning that $E_{n,t} = 1$ indicates a household with education.

In the presence of Harrod-neutral labor-augmenting technological progress, the labor productivity of households ($A_{n,t}$) evolves according to:

$$A_{n,t} = A_{n,t-1}(1 + \delta_{n,t}), \tag{2}$$

where $A_{n,t}$ represents the labor productivity of household n at time t, and $\delta_{n,t}$ is the rate of technological progress. Note that $\delta_{n,t}$ varies across households and depends on education (or

lack of it). More specifically, $\delta_{n,t}$ is a household-specific random variable, drawn from a Normal distribution $N(\mu_{n,t}, \sigma)$, with $\mu_{n,t}, \sigma \in \mathbb{R}^+$. The mean of the distribution ($\mu_{n,t}$) depends on the education status: for households without education ($E_{n,t} = 0$), $\mu_1 > 0$, while for the educated ones ($E_{n,t} = 1$), the mean is drawn from a uniform distribution over the interval $(\mu_1, \mu_2]$. As a consequence, for each worker $\mu_{n,t}$ can take a value within the range $\mu_1 < \mu_{n,t} \leq \mu_2$:

$$\mu_{n,t} = \begin{cases} \mu_1 & \text{if } E_{n,t} = 0 \\ \mu_1 + (\mu_2 - \mu_1)\mathcal{U}, & \text{if } E_{n,t} = 1, \end{cases} \tag{3}$$

where $E_{n,t} \in (0, 1)$ is the binary indicator representing the education status of household n at time t, and $\mathcal{U} \sim \mathcal{U}(0, 1)$. This formulation captures the idea that, even among the educated, differences in realized productivity gains reflect not only effort or skill but also elements of randomness—an insight emphasized by Pluchino et al. (2018) in their analysis of the role of luck in individual success.

Consumption planning. Households' desired nominal consumption ($C^d_{n,t}$) depends on their current disposable income ($YD_{n,t}$) and previously accumulated wealth ($V_{n,t-1}$):

$$C^d_{n,t} = c_{y,n,t} YD_{n,t} + c_v V_{n,t-1}, \quad c_v \in \mathbb{R}^+, \tag{4}$$

where c_v is the propensity to consume out of wealth and $c_{y,n,t}$ is the propensity to consume out of current income which decreases across income deciles.[6] The latter assumption is based on a number of empirical studies finding that wealthier households tend to have lower marginal propensities to consume compared to lower-income households, which translates into higher saving rates among wealthier households (Dynan et al., 2004; Jappelli and Pistaferri, 2014; Saez and Zucman, 2016; Bunn et al., 2018).

Income taxation and wealth accumulation. Total income ($Y_{n,t}$) of a household consists of wages ($W^f_{n,t}$), firm bonuses ($B^f_{n,t}$), bank dividends ($Div_{n,t}$) and interest income on deposits ($Int_{n,t}$):

$$Y_{n,t} = W^f_{n,t} + B^f_{n,t} + Div_{n,t} + Int_{n,t}. \tag{5}$$

A progressive tax rate $\tau_{w,n,t} \in \mathbb{R}^+$ is applied to wage income, while bonuses, interest income and dividends are taxed at a flat rate $\tau_b \in \mathbb{R}^+$. The wage tax rates $\tau_{w,n,t}$ vary by wage income group, as detailed in Table A2. Households' disposable income ($YD_{n,t}$) is what is left of their total income after paying taxes ($T_{n,t}$) plus the unemployment subsidy ($W^{UB}_{n,t}$) in case the household is unemployed:

$$YD_{n,t} = Y_{n,t} - T_{n,t} + W^{UB}_{n,t}. \tag{6}$$

Changes in households' wealth ($V_{n,t}$) equal to their disposable income minus expenditures:

$$\Delta V_{n,t} = V_{n,t-1} + YD_{n,t} - C_{n,t} - EC_t, \tag{7}$$

[6]Note that since households receive firm bonuses and bank dividends only at the end of each period, these income sources are only available for consumption in the following period.

where $C_{n,t}$ are the nominal consumption expenditures and EC_t is the cost of education in case the household has obtained education in the current period. As already mentioned above, households that have reached the end of their work life bequeath any wealth they have accumulated to the next generation in the dynasty. This inherited wealth is the starting wealth for the next generation.

3.3 Firms

Firms' plans involve the decision on their price, desired production, labor demand, wage offer, and credit demand.

Price. Firms set their price ($p_{f,t}$) by applying a fixed mark-up (mu) over unit labor costs of production ($ULC_{f,t}$):

$$p_{f,t} = (1 + mu)ULC_{f,t}, \quad mu \in \mathbb{R}^+. \tag{8}$$

The unit labor costs are computed as the firm's wage offer ($W_{f,t}$) over its productivity ($A_{f,t}$):

$$ULC_{f,t} = \frac{W_{f,t}}{A_{f,t}}. \tag{9}$$

Note that since the firm's productivity ($A_{f,t}$) depends on the productivity of its workforce, effective unit labor costs can only be calculated after the labor market has closed.

Production and employment. Firms determine their desired production ($y^d_{f,t}$) based on their expected real sales and desired change in the stock of real inventories. This means that firms revise their desired production level upward (downward) in case they had sold more (less) than expected in the previous period:

$$y^d_{f,t} = (1 + \iota)s^e_{f,t} - inv_{f,t-1}, \quad \iota \in \mathbb{R}^+, \tag{10}$$

with $s^e = \lambda s_{f,t-1} + (1 - \lambda)s^e_{f,t-1}$, the parameter ι defining the share of desired inventories and $inv_{f,t-1}$ being the firm's previous stock of inventories in real terms.

As we assume a linear technology that employs only labor, the firm's desired production ($y^d_{f,t}$) defines its demand for labor ($N^d_{f,t}$) as follows:

$$N^d_{f,t} = \frac{y^d_{f,t}}{A_{f,t-1}}. \tag{11}$$

If a firm's current demand for labor is higher than its current workforce, it dismisses the number of workers in excess, starting with the least productive ones. In the opposite case, when labor demand is greater than its current workforce, the difference corresponds to the number of vacancies ($vac_{f,t}$) the firms will post in the labor market.

Firms provide a uniform wage offer ($W_{f,t}$) in the labor market as:

$$W_{f,t} = W_{f,t-1}(1 + g_{A_{f,t-1}}), \tag{12}$$

where wage growth is tied to the firm-specific productivity growth, $g_{A_{f,t-1}}$ (in line with Dosi et al., 2017).

Firms produce according to a linear production function with labor as the only input:[7]

$$y_{f,t} = \sum_{n=1}^{N_{f,t}} A_{n,t}^{f} L_{n,t}, \tag{13}$$

where $A_{n,t}^{f}$ is the productivity of the n^{th} employee working for firm f at time t. Without any loss of generality, we assume that $L_{n,t} = 1 \ \forall n, t$. Such linear production process abstracts from capital and other production inputs, focusing solely on labor productivity as the engine of output growth. While this simplification omits important real-world dynamics—such as capital accumulation, innovation or automation—it allows us to focus on the role of education expenditures. As such, the model can capture how disparities in access to education translate into differences in productivity, earnings, and macroeconomic performance.

Firm productivity ($A_{f,t}$) is defined as output per employee:

$$A_{f,t} = \frac{y_{f,t}}{N_{f,t}} \tag{14}$$

where $y_{f,t}$ is output produced by firm f and $N_{f,t}$ denotes its number of employees.

Credit and default. Firms require loans to finance their desired production. A firm's loan demand ($L_{f,t}^{d}$) thus amounts to:

$$L_{f,t}^{d} = W_{f,t} N_{f,t}^{d}, \tag{15}$$

where $W_{f,t}N_{f,t}^{d}$ is corresponds to the firm's expected wage bill.[8]

In every period, firms have to repay any loans they have taken out plus interest. If a firm fails to repay its debt obligations, it goes bankrupt and the bank incur in a non-performing loan. Defaulted firms fire their workforce.

Profits and bonus payments. Firms' realized gross profits ($\Pi_{f,t}$) amount to total sales revenues minus the wage bill and loan interest payments plus any changes in the value of inventories:[9]

$$\Pi_{f,t} = S_{f,t} - WB_{f,t} - L_{f,t} r_l + \Delta INV_{f,t}, \tag{16}$$

with $S_{f,t}$ being nominal sales, the wage bill amounting to $WB_{f,t} = W_{f,t}N_{f,t}$ and $L_{f,t}r_l$ being the interest payments on the loan ($r_l \in \mathbb{R}^+$ is the loan interest rate).

[7] Since firms form production plans under imperfect information about the productivity of individual workers, effective production is bounded by planned output decisions (Eq. 10).

[8] While firms do not hold internal funds in the baseline specification, we verified that simulation results do not significantly change when firms retain a share of their profits.

[9] Throughout the paper, uppercase letters denote inventories valued at current unit costs, whereas lowercase letters denote inventories in real terms (physical units).

Changes in the value of inventories reflect variations in the volume or cost of inventories ($\Delta INV_{f,t} = \Delta inv \cdot UC_{f,t} + \Delta UC \cdot inv_{f,t-1}$). Firms pay taxes ($T_{f,t}$) on any positive profits at a tax rate of $\tau_p \in \mathbb{R}^+$.

Firms pay out bonuses to their own employees ($B_{f,t} = \Pi_{f,t} - T_{f,t} - \Delta INV_{f,t}$). As mentioned above, the distribution of the bonuses to employees ($N_{f,t}$) of the firm is not uniform but instead tied to their individual labor productivity. The share of a firm's bonus for a specific employee n is:

$$Sh^f_{n,t} = \left(\frac{A^f_{n,t}}{\sum_{n=1}^{N_{f,t}} A^f_{n,t}} \right)^{\phi_B}, \quad \phi_B \in \mathbb{R}^+. \tag{17}$$

The parameter ϕ_B defines the degree to which an employee's productivity is rewarded with a share of firm's bonuses. Naturally, the individual shares must be normalized to sum to 1. The bonus received by each employee n of firm f can thus be written as:

$$B^f_{n,t} = \left(\frac{Sh^f_{n,t}}{\sum_{n=1}^{N_{f,t}} Sh^f_{n,t}} \right) B_{f,t}. \tag{18}$$

The parameter ϕ_B thus captures different organizational structures of firms characterized by different degree of income inequality among the employees. When $\phi_B > 1$, employees with higher productivity get a disproportionately larger share of the bonus payments, while $0 < \phi_B < 1$ implies a more equal distribution. This provides a useful framework to analyze the interactions between education, skills and firms organization for the emergence of meritocratic inequality.

3.4 The banking sector

One single bank represents the whole banking and financial sector of our simulated economy.

Credit extension. The bank provides loans to firms. Each firm's borrowing capacity is tied to its previous sales, establishing a credit limit that is proportional to its prior sales revenues (Dosi et al., 2010). This effectively links a firm's loan eligibility to its past performance, ensuring a prudent borrowing approach. The loan supply ($L_{f,t}$) to firm f at time t can be written as:

$$L_{f,t} = min(ltv_f S_{f,t-1}, L^d_{f,t}), \quad ltv_f \in \mathbb{R}^+, \tag{19}$$

where $S_{f,t-1}$ is the sales revenue of firm f in the previous period and ltv_f is a parameter defining the credit-line ceiling. The interest rate on loans is fixed at $r_l \geq 0$ and the duration of loans is set to one period.

Interest and dividend payments. Households keep their wealth ($V_{n,t}$) in the form of remunerated deposits at the commercial bank. More specifically, the bank pays an interest rate of $r_d \geq 0$ on previous deposits, so that the interest income $Int_{n,t}$ of household n received in period t amounts to $V_{n,t-1} r_d$.

The bank's gross profits ($\Pi_{b,t}$) amount to the difference between total loan interests received

and total deposit interests paid minus the sum of non-performing loans:

$$\Pi_{b,t} = L_t r_l - V_t r_d - NPL_t, \tag{20}$$

where L_t is the total of loans, V_t is the total of household deposits and NPL_t is the sum of non-performing loans. The bank pays taxes on any positive profits it has made at a tax rate $\tau_p \in \mathbb{R}^+$.

The net profits are distributed as dividends to households whenever the bank's capital ratio ($CAR_{b,t}$), defined as the bank's net worth over total loans, exceeds the Basel minimum capital requirement (CAR, cf. Bank for International Settlements, 2010):

$$Div_{b,t} = \begin{cases} min(\Pi_{b,t} - T_{b,t}, (CAR_{b,t} - CAR)L_t), & \text{if} \quad CAR_{b,t} > CAR \\ 0 & \text{otherwise.} \end{cases} \tag{21}$$

The bank dividends are proportionally allocated according to households' wealth ($V_{n,t}$). The dividends received by each household n can thus be written as:

$$Div_{n,t} = \left(\frac{V_{n,t}}{\sum_{n=1}^{N} V_{n,t}} \right) Div_{b,t}. \tag{22}$$

The bank's undistributed profits, if any, goes towards its equity. In the case of a net loss, $Div_{b,t} = 0$. If the commercial bank's equity becomes negative, indicating a default, all households contribute proportionally to their wealth to restore the minimum capital requirement CAR.[10]

3.5 The government

The government sector contributes to the aggregate demand directly with public consumption and indirectly with transfers to unemployed households. Moreover, the government provides educational services which are financed by households' educational expenditures (EC_t).[11]

The government purchases a portion of the total production from firms to provide public goods and services (G_t). Desired government expenditures (G_t^d) on goods and services represent planned public consumption and grows in line with average household productivity growth. As in the case of households, these expenditure plans do not automatically translate into effective consumption, which is endogenously determined in the goods market described in the following section. Households' total educational expenditures (EC_t) are collected by the government and finance the provision of educational services. The cost of provision of educational services consists of the remuneration of teachers who fully consume their income. The government pays unemployment benefits (UB_t) to households without a job. The unemployment benefits are a

[10] While in the following simulations bank defaults do not occur, the model is specified to account for this possibility.

[11] Future work could explicitly model an education sector with its own budget and workforce, as well as distinguish between private and public education.

share ω of the average wage in the economy $\bar{W}_t$, with $\omega \in \mathbb{R}^+$. The government collects taxes on wages, bonuses and dividends from households and on profits from firms and the bank.

The public deficit ($PDef_t$) amounts to the difference between total government expenditures and revenues:

$$PDef_t = G_t + UB_t - T_t. \tag{23}$$

For simplicity, we assume that government debt (GD_t) does not pay any interest.

For simplicity, we assume that government debt (GD_t) does not pay any interest. [12]Accordingly, its evolution is entirely determined by the government's fiscal balance:

$$GD_t = GD_{t-1} + PDef_t. \tag{24}$$

Note that the government does not run a balanced budget, but, as shown in Section 4, the public debt-to-GDP ratio remains stable over time.

3.6 Market interactions

Firms and households interact in the labor and goods markets following a common matching protocol akin to that in Guerini et al. (2018) and Ciambezi et al. (2025). Such a protocol allows for local market interactions and for the possible emergence of coordination failures within and across markets and the rise of endogenous business cycles.

Labor market interactions. As the labor market opens, firms post their number of vacancies ($vac_{f,t}$) and their wage offer ($W_{f,t}$). Workers then decide to apply for any vacancy with a probability increasing in the wage offered by the firm. More specifically, a worker will apply for a job ($\Phi^{LM}_{n,t} = 1$) or not ($\Phi^{LM}_{n,t} = 0$) according to the following Bernoulli trial:

$$\Phi^{LM}_{n,t} = \begin{cases} 0 & \text{with probability } p^{LM}_{f,t} \\ 1 & \text{with probability } 1 - p^{LM}_{f,t} \end{cases} \tag{25}$$

The probability of applying ($1 - p^{LM}_{f,t}$) is proportional to the wage offered by the firm relative to the average wage offer ($\bar{W}_t$):

$$1 - p^{LM}_{f,t} = 1 - \frac{1}{\rho^{LM}}[1 - (\frac{W_{f,t} - \bar{W}_t}{\bar{W}_t})], \tag{26}$$

where $\rho_{LM} \in (1, \infty)$ defines the degree of imperfect information in the labor market. The lower ρ_{LM}, the more sensitive is the probability to apply to the deviation of the wage offer from the average wage.

[12]As a robustness check, we also tested an alternative specification where the household sector buys the government debt and receives interest payments. While this extension changes the levels of certain distributive and macroeconomic variables, the qualitative dynamics and main results remain robust across different levels of interest rates. In particular, for all interest rates considered (2.5, 5 and 10%), the public debt-to-GDP ratio remains stable over time. This extension promises an interesting avenue for future research with a richer representation of financial assets.

After all households have applied, firms proceed to hiring employees from the pool of applicants. Firms do not observe workers' individual productivity prior to hiring, reflecting imperfect information in the labor market, and therefore use education as a signaling device (Arrow, 1973; Spence, 1973; Stiglitz, 1975). As such, firms rank applicants by educational attainment and first hire workers with education; and if vacancies remain, firms then hire applicants without. Within each educational group, applicants are ranked randomly. Hiring continues until either all vacancies are filled or the pool of applicants is exhausted. As a result, the effective number of employees working for each firm ($N_{f,t}$) is determined by the availability of applicants relative to posted vacancies.

Workers remain at the same firm until retirement unless the firm defaults on its loan and dismisses its workforce.

Goods market interaction. The goods market matches firms' output with consumption demand from households and the government. Matching of households and firms in the goods market works in a similar way as in the labor market. Households decide to queue for goods sold by a specific firm ($\Phi^{GM}_{n,t} = 1$) or not ($\Phi^{GM}_{n,t} = 0$) according to the following Bernoulli trial:

$$\Phi^{GM}_{n,t} = \begin{cases} 0 & \text{with probability } 1 - p^{GM}_{f,t} \\ 1 & \text{with probability } p^{GM}_{f,t} \end{cases} \tag{27}$$

The probability of queuing ($1 - p^{GM}_{f,t}$) falls with the price charged by the firm relative to the average market-price ($\bar{p}_t$):

$$p^{GM}_{f,t} = \frac{1}{\rho^{GM}}[1 - (\frac{p_{f,t} - \bar{p}_t}{\bar{p}_t})], \tag{28}$$

where $\rho_{GM} \in (1, \infty)$ defines the degree of imperfect information there is in the goods market. The higher its value, the more sensitive households are in price differences between firms when selecting a supplier.

Once households have queued, firms' effective sales to households are determined by the short side of the market. If desired household consumption exceeds firm production ($c^d_{f,t} > y_{f,t}$), households are symmetrically rationed.

After household demand has been realized, the government planned public consumption is evenly allocated across firms. Effective government consumption thus depends on the availability of remaining supply of each firm.

As the goods market closes, households and the government determine their effective consumption levels, which may fall short of planned demand due to supply constraints. Firms' effective sales ($S_{f,t}$) are given by the sum of private and public consumption, with any unsold output accumulated as inventories ($inv_{f,t}$).

3.7 Macroeconomic aggregates

At the end of each period t, macroeconomic variables (e.g., GDP) are directly computed by aggregating individual quantities. This section defines the main macroeconomic aggregates used

in the model, namely aggregate consumption, gross domestic product, productivity measures and inflation.

Aggregate consumption. Aggregate private consumption is defined as the sum of consumption expenditures across all households:

$$C_t \;=\; \sum_{n \in N} C_{n,t}, \tag{29}$$

where $C_{n,t}$ denotes nominal consumption by household n in period t and N is the set of dynasties of households. Together with public consumption (G_t), it determines aggregate demand and realized sales in the economy.

Gross domestic product. Nominal GDP (Y_t) can be calculated from the production, expenditure, or income side:

$$\begin{aligned} Y_t &= \underbrace{\sum_{f \in F} \Big(S_{f,t} + \Delta inv_{f,t} \cdot ULC_{f,t} \Big)}_{\text{Production side}} = \underbrace{\Big(C_t + G_t + I_t \Big)}_{\text{Expenditure side}} \\ &= \underbrace{\sum_{f \in F} WB_{f,t} + \sum_{f \in F} \Big(\Pi_{f,t} - \Delta ULC_{f,t} \cdot inv_{f,t-1} \Big) + \Pi_{b,t}}_{\text{Income side}} \end{aligned} \tag{30}$$

From the production side, nominal GDP is given by total sales revenues plus changes in inventories valued at their unit cost. From the expenditure side, it is the sum of private and public consumption and investment in the form of inventory accumulation ($I_t \equiv \sum_{f \in F} \Delta inv_{f,t} \cdot ULC_{f,t}$). Finally, from the income side, nominal GDP equals the sum of compensation of employees, gross profits of firms (excluding any inventory valuation adjustments) and gross profits of the banking sector.

Productivity. At the micro level, firm productivity is defined as output per employee (Eq. 14). Aggregate firm productivity is constructed as a sales-weighted average:

$$A_t^F \;=\; \sum_{f \in F} f_{f,t}\, A_{f,t}, \quad \text{with} \quad f_{f,t} = \frac{S_{f,t}}{S_t}. \tag{31}$$

Aggregate household productivity is defined as the average of individual household productivities:

$$A_t^N \;=\; \frac{1}{N} \sum_{n \in N} A_{n,t}, \tag{32}$$

where $A_{n,t}$ captures the productivity of household n in period t.

Inflation. The aggregate price level is defined as the sales-weighted average of firm prices:

$$p_t \;=\; \sum_{f \in F} f_{f,t}\, p_{f,t}. \tag{33}$$

Inflation is then computed as the period-over-period growth of the aggregate price level:

$$\pi_t \;=\; \frac{p_t - p_{t-1}}{p_{t-1}}. \tag{34}$$

4 Simulation results

The macro and micro dynamics of the model are explored through a series of computational simulations, which shed light onto the evolving macroeconomic outcomes concerning output, inequality and education under different scenarios. After outlining our simulation and scenario setups (Sections 4.1, we describe and empirically validate the baseline scenario (Section 4.2). We then conduct a set of simulation exercises designed to assess the sensitivity of our results to the cost structure of education, the distribution of bonuses across employees and their possible interactions (Section 4.3). Finally, a policy scenario examining the effects of targeted educational subsidies for lower-income households on macroeconomic performance and distributional outcomes (Section 4.4).

4.1 Simulation and scenario setups

The model is empirically calibrated to the U.S. economy and designed to replicate key stylized facts on inequality and social mobility. The model parameters are detailed in Table A1. The main parameter values and initial conditions are taken from U.S. time series data or empirical studies. Specifically, the average propensities to consume (APCs) by income decile, shown in Table A2 are in line with empirical studies (Dynan et al., 2004; Mian et al., 2020). The initial wealth distribution is calibrated to the U.S. 1980 wealth decile shares. Wage tax rates are implemented as a progressive schedule with three brackets (see Table A2) calibrated on empirical averages reported by OECD (2024). The tax rates on profits and dividends, shown in Table A1, align with the U.S. federal corporate income tax rate. Additionally, the firms' pricing mark-up is chosen to ensure that the average wage share in the economy corresponds to the wage share in GDP, with a long-term average of approximately 62% (Figure 1, cf. Alvaredo et al., 2018). This calibration ensures that the model remains consistent with key macroeconomic relationships and observed income and wealth distribution patterns.

The *baseline* specification of the model is designed to be in tune with the long-run empirical trends observed in the United States, which show a growing disconnect between education costs, inflation, and average real wage growth (see Figure 2b). In particular, we assume an increase in the relative cost of education over time via a permanent surge in the parameter ϕ_{EC} in Eq. 1 in period 201. This change mimics the shift that occurred during the 1980s, when education costs began to rise rapidly (Archibald and Feldman, 2008; Markovits, 2019), and captures how accelerated growth in education costs relative to wages can restrict access to education and hinder intergenerational mobility. The baseline scenario is empirically validated in Section 4.2.

We then explore *three scenarios* resulting from the variation of the parameters concerning education costs and bonus compensation (cf. Section 4.3). Figure 5 shows the parameter space of ϕ_B and ϕ_{EC} explored in the baseline and in the following three simulation scenarios:

1. The *education cost* scenario (cf. Section 4.3.1) focuses on households' ability to afford education. By simulating environments characterized by low, medium, and high rates of education cost growth relative to wage growth, we assess how changes in affordability

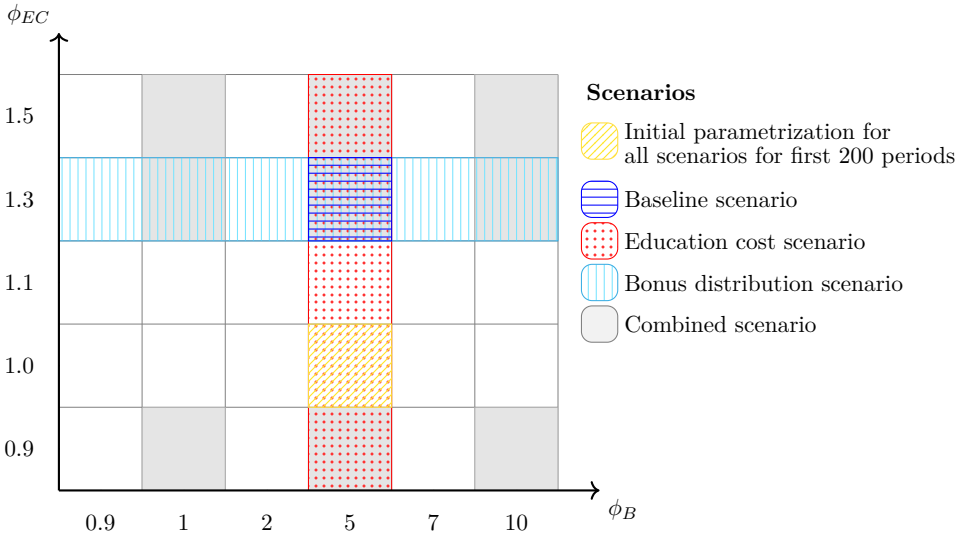
affect educational attainment, the distribution of human capital, and subsequent economic outcomes. This analysis sheds light on the role of education as a channel of social mobility and on its implications for long-run income inequality and economic growth.

2. The *bonus distribution* scenario (cf. Section 4.3.2) studies how changes in compensation inequality among workers affect macroeconomic outcomes. We perform such an analysis by modifying the bonus distribution parameter (ϕ_B) in Eq. 17. This scenario is designed to provide insights into how variations in the income distribution mechanisms can enhance or limit access to education, as well as their broader impact on output growth.

3. The *combined* scenario (cf. Section 4.3.3) considers both changes to the education cost parameter (ϕ_{EC}) and bonus distribution parameter (ϕ_B) in order to study the possible interactions between these two dimensions and their joint effects on economic dynamics. In particular, we search for potential synergies or trade-offs emerging from these dimensions, offering a more holistic view of how these two factors can influence economic dynamics in a meritocratic system, possibly uncovering distinct regimes characterized by varying levels of inequality and growth.

Finally, the last *policy scenario* (cf. Section 4.4) introduces a stylized education policy experiment in which the government subsidizes educational access for households at the lower end of the wealth distribution. The policy provides a full subsidy to households that are of eligible age, have not yet acquired education, and are unable to afford its cost. The intervention is implemented for different coverage levels, targeting the poorest $x\%$ of households with $x \in (5, 10, 20)$, allowing us to assess the distributional and macroeconomic effects of relaxing financial barriers to education. This scenario is built on the baseline parameterization.

Figure 5: Parameter space explored through scenario analyses



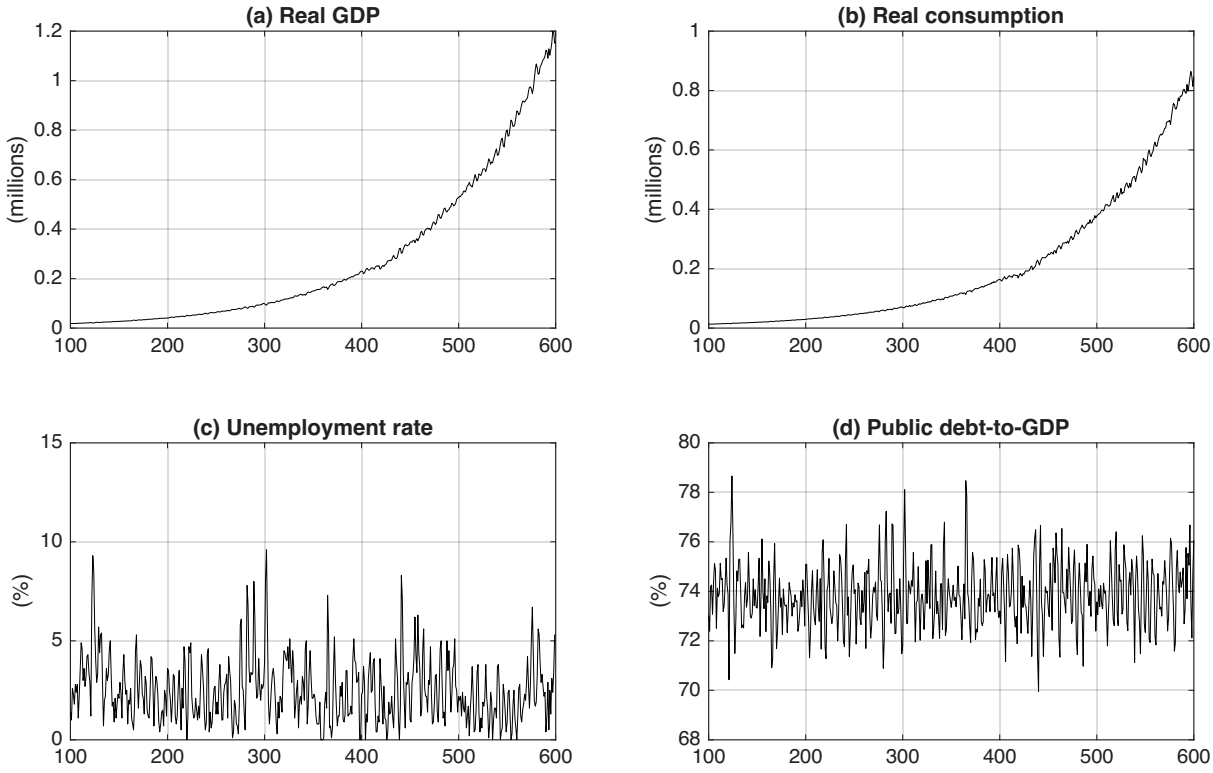
Notes: Simulation scenarios as a function of the education cost (ϕ_{EC}) and of the bonus distribution (ϕ_B) parameters. The yellow-shaded region represents the initial parameterization common to all scenarios during the first 200 periods of the simulation. Other shaded regions correspond to parameter combinations applied from period 201 onward, specific to each scenario.

4.2 Empirical validation of the baseline scenario

We start by providing a broad description of the macroeconomic dynamics in the baseline scenario, and then zoom in on education, inequality and mobility to discuss in greater detail the mechanisms at play. Note that in such a scenario we assume increasing education costs relative to average wage growth (ϕ_{EC} in Eq. 1 increases from 1.0 to 1.3 in period 201). This is consistent with empirical observations of rising tuition fees and the growing cost of higher education in developed economies, particularly in the U.S., where college tuition has significantly outpaced inflation and wage growth over the past few decades (Goldin and Katz, 2018; Ma and Pender, 2023).

Figure 6 displays the macroeconomic time series generated by one typical Monte Carlo run for real GDP, real consumption, unemployment rate and public debt-to-GDP. The trajectory of real GDP and consumption follows a clear log-linear growth pattern. Both the unemployment rate and the public debt-to-GDP ratio fluctuate around relatively low and stable levels. The wage share in our model also remains stable (Table 1) as a consequence of the fixed mark-up pricing rule specified in Eq. 8. While this assumption abstracts from the empirically observed decline in the labor share in many advanced economies (see Figure 1a for the U.S. economy), it allows us to focus more clearly on the evolution of personal inequality—which has intensified significantly more in recent decades than functional inequality, especially as the richest in terms of capital income also earn increasing shares of labor income as well (Berman and Milanovic, 2024)—and to isolate its underlying drivers.

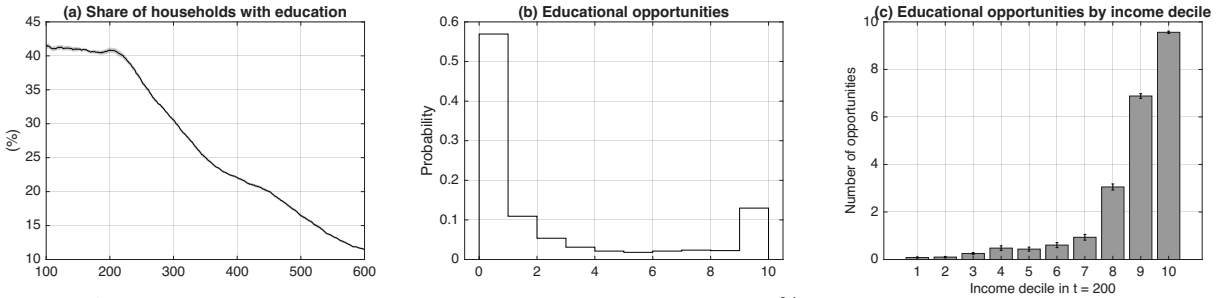
Figure 6: Baseline scenario - macroeconomic time series from one typical Monte Carlo run



Notes: Real GDP (a), real consumption (b), unemployment rate (c), and public debt-to-GDP ratio (d).

The increase in education costs simulated in this baseline scenario progressively reduces the share of households obtaining education (Figure 7, left panel). The falling educational opportunities are also highly polarized: a large share of household dynasties are never able to afford education, while others are able to finance it multiple times over the course of the simulation (Figure 7, central panel). This polarization maps directly into the income distribution, as the dynasties that are in the highest income deciles in period 200 are consistently able to afford education expenses for multiple generations (Figure 7, right panel).

Figure 7: Baseline scenario - key education-related variables

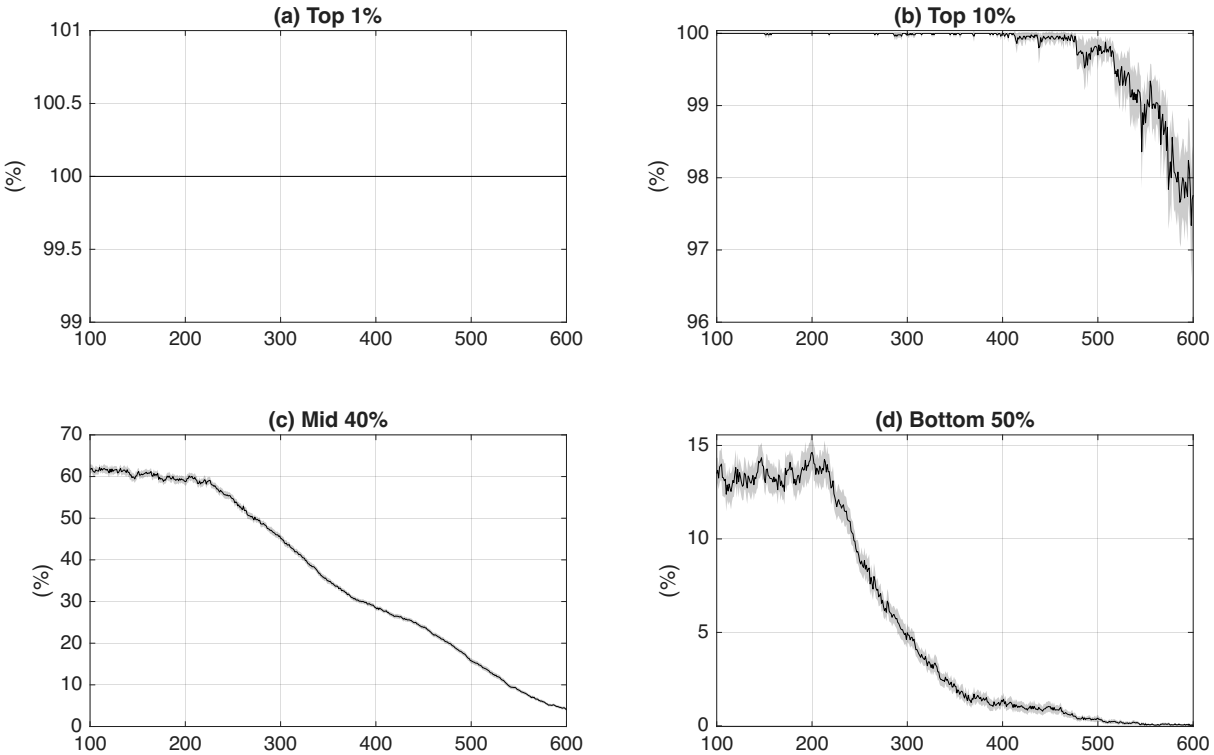


Notes: Average share of households with education over time with 95% confidence bands across 50 MC runs (a), distribution of realized educational opportunities at across households the end of the simulation (b), average number of educational opportunities by income decile in period 200 with error bars indicating one standard deviation across 50 MC runs (c).

Coherently, in Figure 8 we can observe that the decline in the share of households with education is not even across income groups over time. While the top 1% of households in terms of income continue to maintain their educational attainment, lower-income households are increasingly excluded from educational opportunities. This widening gap underscores the growing disparity in educational access, where the rising costs of education disproportionately affect those in the lower end of the income distribution. While the bottom 50% group displays extremely low values in education shares, it is most notably the middle-income group that is losing ground, reflecting a broader squeeze on the middle class that has been discussed in recent literature (Markovits, 2019).[13] Consequently, the economic opportunities tied to education are becoming increasingly concentrated among the wealthiest households, exacerbating income inequalities and hindering social mobility. Interestingly, rising education costs marginally affect also households in the lower percentiles of the top 10%, reducing the share of households able to afford education, reinforcing the privileged position of the top 1% with respect to the rest of the income distribution.

[13]Recall that in the model, the number of "applications" is fixed because we do not model the behavioral factors influencing the decision to pursue education—everyone seeks education if they have the opportunity. Consequently, the overall decline in education shares reflects decreasing acceptance rates over time. Moreover, the pronounced drop in the share of households with education within the middle 40% mirrors empirical evidence showing that middle-class students have lower-than-average attendance rates at top schools and Ivy League institutions (Chetty et al., 2026).

Figure 8: Baseline scenario - share of households with education across different income groups



Notes: Top 1% (a), top 10% (b), mid 40% (c), bottom 50% (d). Values refer to 50 MC averages with shaded 95% confidence bands.

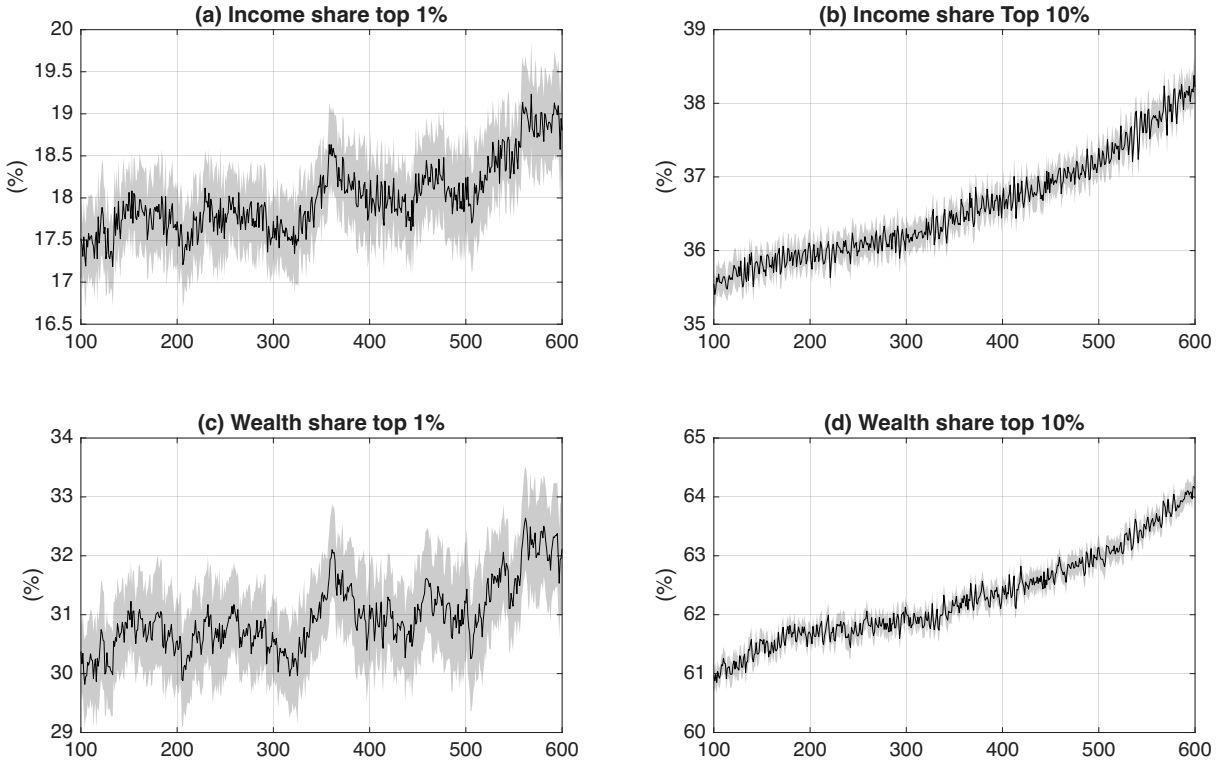
The decline in access to education has significant macroeconomic implications for long-run growth, inequality and social mobility, consistent with concerns about the consequences of barriers to educational access (e.g., Stiglitz, 2012; OECD, 2018). The model's capacity to endogenously generate increasing income and wealth inequality is shown in Table 1, which reports the evolution of the Gini coefficients and the income and wealth shares of different quantiles. First, wealth is more concentrated than income, consistent with a well-established stylized fact in inequality research . Second, all inequality indicators—both for income and wealth—exhibit an upward trend, reflecting widening disparities driven by unequal access to education and the resulting divergence in household productivity. The sharp rise in the top income and wealth shares (see also Figure 9) mirrors empirical patterns observed in many advanced economies in recent decades, where income distribution has become increasingly polarized and wealth highly concentrated (Piketty and Saez, 2003; Chetty et al., 2014; Piketty et al., 2018; Acciari et al., 2024; Guzzardi et al., 2024). Notably, the model closely replicates the top 1% pre-tax income and net wealth shares observed in the United States (empirically, 20.87 for income and 34.9 for wealth in 2022, Alvaredo et al., 2022).[14]

The model generates plausible patterns of income mobility (see Table 1) in response to increasing education inequality. Indeed, simulations show high income immobility at the top (OECD, 2018; Barone and Mocetti, 2021), with 76-82% of households starting in the top 10%

[14]The introduction of a financial asset market is an important extension of the model which we plan to develop in the future. This extension would allow to possibly reinforce wealth disparities in the model, and to study the interaction between financial crises and wealth inequality.

persistently remaining there over time. In contrast, the middle 40% experiences increasing downward mobility.

Figure 9: Baseline scenario - inequality indices



Notes: Share of income (top row) and wealth (bottom row) accrued by the top 1% (left panels) and top 10% (right panels). Values refer to 50 MC averages with 95% confidence bands.

The negative impact of the restricted access to education leads not only to a surge of inequalities, but also to a deceleration of economic growth. However, such result gradually emerges only over the long run. Indeed, GDP and consumption initially maintain their steady growth trajectories, while the slowdown of economic activity becomes apparent in the last part of the simulations (see Table 1). This intriguing result depends on the intricate relationship between education access, potential and effective productivity growth, and the evolution of aggregate demand.

As the share of households able to obtain education falls, the economy's *potential productivity* growth declines (cf. Eq. 2). This reduction is directly visible in the falling average of individual productivity growth rates across households (Table 1). However, at the aggregate level potential productivity growth can remain relatively elevated for some time because the households that continue to obtain education are generally those with higher (initial) productivity levels and therefore account for a large share of total production capacity. Aggregate potential productivity growth thus depends not only on individual productivity gains but but also on the distribution of these gains across the workforce (see Appendix B for further details).

Macroeconomic growth is ultimately determined by the *effective productivity*, i.e. the productivity that is actually realized given the prevailing demand conditions. Effective productivity

thus depends on the evolution of aggregate demand, which in turns is affected by the income distribution (Eq. 4). Moreover, as consumption depends both on current income and on (previously accumulated) wealth, demand can remain resilient for some time despite declining average productivity growth. As a result, effective output growth slows down only gradually as demand becomes insufficient to absorb productive capacity.

To sum up, the increasing educational exclusion mainly affects low- and middle-income households in the short-run, but it gradually spreads to the macroeconomic level eroding the growth capacity of the economy due to persistently restricted educational access and tighter demand-side constraints (see Table 1). Our agent-based model thus allows to uncover the cross-frequency negative impact of education resulting from the interaction of supply and demand factors emerging at different levels of aggregation. This brings relevant policy implications that will be further explored in the following scenarios.

Table 1: Baseline scenario - summary statistics of key variables

Variable	Period 100-200	Period 200-300	Period 300-400	Period 400-500	Period 500-600
Macroeconomic variables					
GDP growth (%)	0.86 (0.004)	0.88 (0.004)	0.86 (0.005)	0.86 (0.004)	0.84 (0.005)
Consumption growth (%)	0.86 (0.003)	0.88 (0.004)	0.87 (0.005)	0.87 (0.005)	0.84 (0.005)
Household productivity growth (%)	0.70 (0.000)	0.68 (0.000)	0.63 (0.000)	0.60 (0.000)	0.57 (0.000)
Unemployment rate (%)	2.84 (0.036)	2.73 (0.045)	2.63 (0.040)	2.52 (0.033)	2.52 (0.049)
Wage share (%)	62.27 (0.002)	62.27 (0.002)	62.27 (0.002)	62.27 (0.002)	62.27 (0.001)
Public debt/GDP (%)	73.93 (0.016)	73.82 (0.017)	73.92 (0.017)	73.88 (0.015)	74.11 (0.023)
Education-related variables					
Education cost growth (%)	0.84 (0.003)	1.12 (0.004)	1.11 (0.004)	1.09 (0.005)	1.07 (0.005)
Education share (%)	40.93 (0.101)	36.23 (0.106)	25.50 (0.081)	19.65 (0.074)	13.64 (0.084)
Education share top 1 (%)	100.00 (0.000)	100.00 (0.000)	100.00 (0.000)	100.00 (0.000)	100.00 (0.000)
Education share top 10 (%)	100.00 (0.000)	100.00 (0.002)	100.00 (0.001)	99.89 (0.028)	98.90 (0.107)
Education share mid 40 (%)	60.58 (0.212)	53.73 (0.205)	35.77 (0.195)	23.16 (0.198)	9.21 (0.203)
Education share bottom 50 (%)	13.39 (0.199)	9.48 (0.147)	2.39 (0.069)	0.80 (0.069)	0.13 (0.018)
Inequality indices					
Gini Income	0.33 (0.000)	0.33 (0.000)	0.34 (0.001)	0.35 (0.001)	0.36 (0.002)
Gini Wealth	0.70 (0.000)	0.71 (0.000)	0.71 (0.000)	0.71 (0.000)	0.72 (0.000)
Income share top 1 (%)	17.69 (0.136)	17.73 (0.135)	17.95 (0.137)	18.04 (0.154)	18.58 (0.189)
Income share top 10 (%)	35.78 (0.037)	36.06 (0.041)	36.43 (0.038)	36.92 (0.045)	37.71 (0.044)
Income share mid 40 (%)	32.15 (0.048)	32.19 (0.048)	32.15 (0.077)	32.20 (0.090)	32.17 (0.128)
Income share bottom 50 (%)	32.07 (0.038)	31.76 (0.057)	31.42 (0.078)	30.88 (0.107)	30.13 (0.143)
Wealth share top 1 (%)	30.57 (0.236)	30.64 (0.234)	30.92 (0.238)	30.99 (0.265)	31.68 (0.320)
Wealth share top 10 (%)	61.39 (0.055)	61.78 (0.061)	62.11 (0.056)	62.67 (0.062)	63.51 (0.057)
Wealth share mid 40 (%)	29.79 (0.061)	29.59 (0.060)	29.27 (0.074)	28.87 (0.075)	28.23 (0.095)
Wealth share Bottom 50 (%)	8.82 (0.026)	8.63 (0.032)	8.62 (0.043)	8.46 (0.052)	8.26 (0.065)
Bonus share Top 10 (%)	89.49 (0.107)	90.36 (0.116)	91.40 (0.110)	92.79 (0.120)	94.98 (0.111)
Social mobility indices					
Top 10 persistence (%)	76.35 (0.72)	76.37 (0.67)	76.72 (0.58)	78.02 (0.71)	82.29 (0.63)
Mid 40 persistence (%)	58.39 (0.53)	58.28 (0.51)	56.77 (0.44)	53.88 (0.55)	50.86 (0.51)
Mid 40 upward mobility (%)	5.94 (0.18)	5.93 (0.17)	5.92 (0.16)	5.52 (0.18)	4.53 (0.16)
Mid 40 downward mobility (%)	35.67 (0.50)	35.79 (0.46)	37.31 (0.40)	40.60 (0.45)	44.61 (0.46)
Bottom 50 persistence (%)	69.65 (0.40)	69.21 (0.39)	67.35 (0.40)	65.51 (0.43)	62.03 (0.43)

Notes: Values represent averages across 50 Monte Carlo runs for each variable over the specified time periods in the column headers. Standard errors are reported in parentheses. Income shares are post-tax. Indices for social mobility persistence indicate the share of households that were in a given income group at the start of the specified time period and remained in the same group at its end.

4.3 Education and bonus scenarios

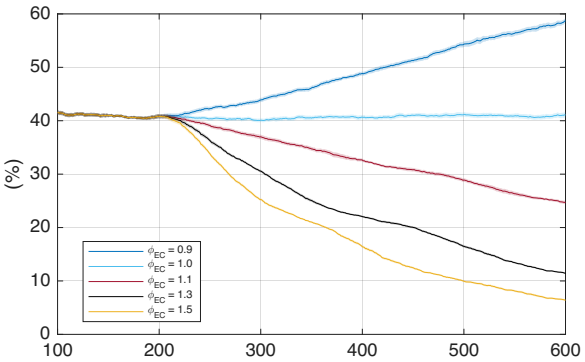
We now explore the scenarios depicted in Figure 5 resulting from the variation of the ϕ_{EC} and ϕ_B parameters.

4.3.1 Education cost scenario

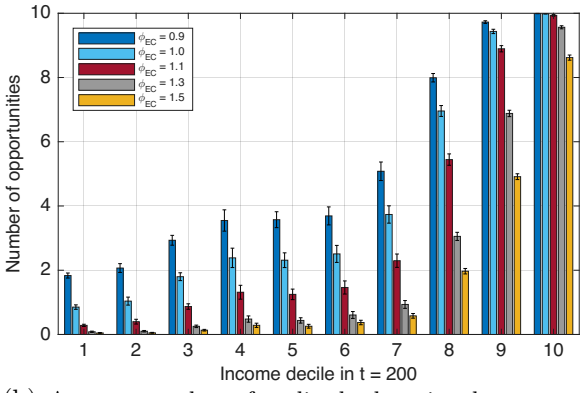
The benchmark scenario shows that when the growth of education cost outpaces that of wages —mimicking the rapid rise in education costs observed since the 1980s (Archibald and Feldman, 2008; Ma and Pender, 2023)— the educational access falls, especially for lower-income groups. To better understand the effects of alternative educational cost structures on the performance of the economy, we vary the parameter ϕ_{EC} in Eq. 1 across a range of values (i.e., 0.9, 1.0, 1.1 and 1.5) from period 201 onward,[15] and we compare the outcomes with the baseline scenario.

As expected, higher values of ϕ_{EC} result in less affordable education and, in turn, a smaller share of households getting education (cf. Figure 10a). By ranking household dynasties by income deciles in period 200, Figure 10b shows that the decline in educational attainment in the period 201-600 occurs throughout the income distribution. However, the top decile continues to afford education across multiple generations, even under the highest cost growth. In contrast, the middle class significantly loses ground, while the bottom decile sees virtually no opportunity, starting from already low levels.

Figure 10: Education cost scenario - education-related variables



(a) Share of households with education for different levels of the education cost parameter ϕ_{EC}. Values refer to 50 MC averages with shaded 95% confidence bands. The baseline scenario corresponds to $\phi_{EC} = 1.3$.



(b) Average number of realized educational opportunities between periods 201 and 600 by income decile in period 200 and for different levels of the education cost parameter ϕ_{EC}. Values represent averages over 50 Monte Carlo runs, with error bars denoting one standard deviation.

The impact of varying ϕ_{EC} on education and inequality is detailed in Table 2, which shows summary statistics across experiments in relative terms with respect to the baseline. Lower education costs have a positive impact especially on the households belonging to the middle 40%

[15] We cap ϕ_{EC} at 1.5 because, at this rate–implying education costs grow 50% faster than wages–access to education quickly becomes prohibitively expensive for the majority of households (see Table 2).

and bottom 50% of the income distribution. In turn, this reduces income inequality: in the most favorable cost scenario, the middle 40% is able to increase its wealth share by 5% and its income share by 2%; the bottom 50% sees a 2% rise in its income share, while changes in the wealth share are generally not statistically significant; the top 10% income share decreases by up to 3%, and top 10% wealth concentration decreases by 1%. The effects are even more pronounced for the top 1%, whose income share falls by 4% and wealth share by 3%. Conversely, as education costs rise more rapidly than wages, the bottom 50% and middle 40% become increasingly excluded from educational opportunities, exacerbating income inequality and constraining social mobility. At the same time, top income and wealth shares rise as educational opportunities become more restricted: in the most extreme scenario, the top 1% income share rise by 4% relative to the baseline, while the top 1% wealth share increases by 3%. Notably, the top 10% of income earners generally manage to increase their income shares as education costs rise, but under very high cost growth they begin to lose educational access, whereas the top 1% remain unaffected.

Table 2: Education cost scenario - summary statistics of key variables relative to the baseline

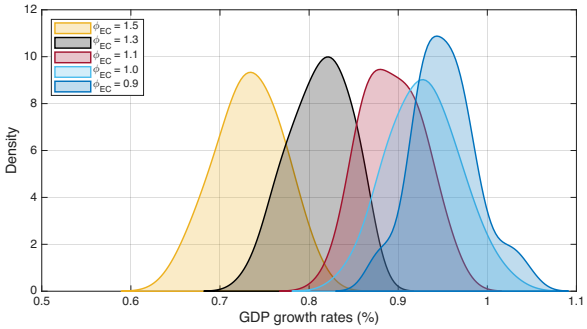
Variable	Baseline $\phi_{EC} = 1.3$	Exp 1 $\phi_{EC} = 0.9$	Exp 2 $\phi_{EC} = 1.0$	Exp 3 $\phi_{EC} = 1.1$	Exp 4 $\phi_{EC} = 1.5$
Macroeconomic variables					
GDP growth (%)	0.84	1.16***	1.13***	1.10***	0.91***
Consumption growth (%)	0.84	1.16***	1.13***	1.10***	0.91***
Avg. household productivity growth (%)	0.57	1.38***	1.24***	1.11***	0.95***
Unemployment rate (%)	2.52	0.94**	0.97	1.01	1.09***
Wage share (%)	62.27	1.00	1.00	1.00	1.00
Public debt/GDP (%)	74.11	0.99***	0.99***	1.00***	1.00***
Education-related variables					
Education cost growth (%)	1.07	0.81***	0.88***	0.92***	1.06***
Education share (%)	13.64	4.14***	3.00***	1.95***	0.60***
Education share top 1 (%)	100.00	1.00	1.00	1.00	1.00
Education share top 10 (%)	98.90	1.01***	1.01***	1.01***	0.80***
Education share mid 40 (%)	9.21	7.98***	6.14***	3.89***	0.05***
Education share bottom 50 (%)	0.13	269.24***	130.94***	35.03***	0.06***
Inequality indices					
Gini Income	0.36	0.97***	0.97***	0.98***	1.02***
Gini Wealth	0.72	1.01***	1.00	1.00	1.00***
Income share top 1 (%)	18.58	0.96***	0.96***	0.99	1.04***
Income share top 10 (%)	37.71	0.97***	0.97***	0.98***	1.02***
Income share mid 40 (%)	32.17	1.02***	1.01***	1.01	0.98***
Income share bottom 50 (%)	30.13	1.02***	1.02***	1.02***	0.99
Wealth share top 1 (%)	31.68	0.97**	0.97*	1.00	1.03**
Wealth share top 10 (%)	63.51	0.99***	0.99***	0.99***	1.02***
Wealth share mid 40 (%)	28.23	1.05***	1.04***	1.02***	0.96***
Wealth share bottom 50 (%)	8.26	0.94***	0.97***	1.00	1.01
Bonus share top 10 (%)	94.98	0.96***	0.97***	0.98***	1.03***

Notes: For the baseline, values report the Monte Carlo average of each variable over periods 500–600. For the non-baseline scenarios, entries report the ratio of the Monte Carlo mean in the experiment to the Monte Carlo mean in the baseline. Significance stars indicate rejection of the null hypothesis of no difference from baseline: *** p<0.01, ** p<0.05, * p<0.10. Income shares are post-tax.

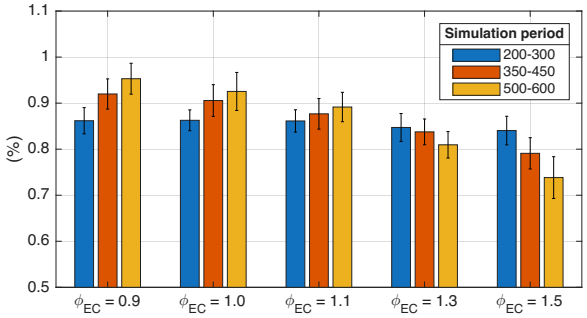
Educational cost dynamics directly affect the long-run performance of the economy. As shown in Figure 11a, higher values of ϕ_{EC} reduce average GDP growth and increase the dispersion of growth rates. When comparing the growth dynamics over time across the different

experiments, Figure 11b shows that average growth is sustained under low education cost growth but declines progressively in high-cost scenarios, indicating that rising education costs slow long-term growth. Higher education costs also dampen household consumption and, in combination with reduced productive capacity, generate increasing coordination failures between supply and demand, leading to higher unemployment (cf. Table 2) and increased volatility (cf. Figure 11a).

Figure 11: Education cost scenario - real GDP growth



(a) Distribution of average GDP growth between periods 500 and 600 for 50 MC runs across experiments with varying education cost parameters ϕ_{EC}.



(b) Average real GDP growth across experiments with varying education cost parameters. Values represent averages over 50 Monte Carlo runs for the indicated time spans, with error bars denoting one standard deviation. The baseline scenario corresponds to $\phi_{EC} = 1.3$.

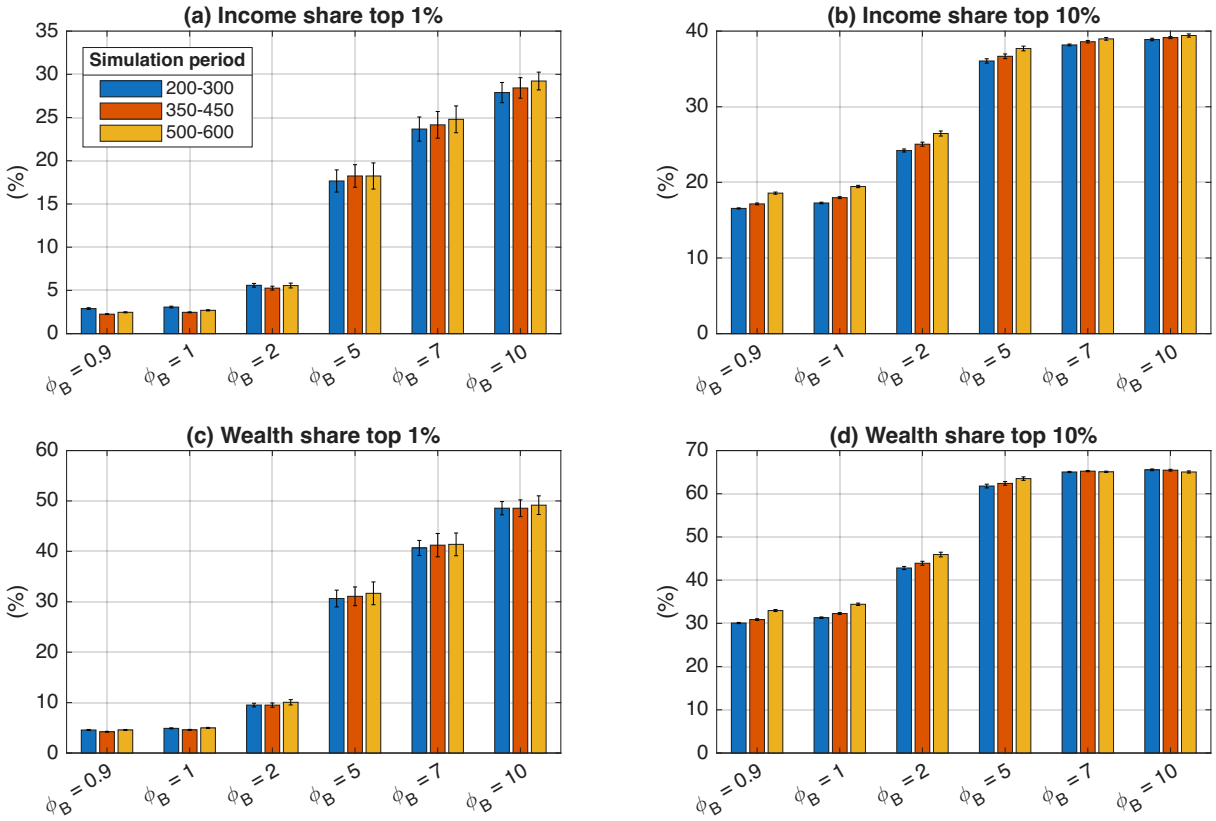
Overall, our results show that even small differences in educational opportunities can amplify inequality over time, thus reproducing the well-documented link between barriers to education, inequality, and reduced intergenerational mobility (see Chetty et al., 2014; Corak, 2013). In turns, higher inequality undermines the growth prospects of the economy (in line with the empirical evidence in OECD, 2015; Berg and Ostry, 2017; Berg et al., 2018), and, by depressing consumption, increases unemployment and exacerbate business fluctuations (Stiglitz, 2012; Fitoussi and Saraceno, 2010). From a policy perspective, our findings suggest that lowering barriers to education constitutes a relevant *pre-distributive* intervention to reduce inequality (Blanchet et al., 2022; Bozio et al., 2024), while supporting long-run growth (Bharti et al., 2026).

4.3.2 Bonus distribution scenario

In this second scenario, we focus on the impact of altering the parameter ϕ_B (cf Eq. 17) which governs the distribution of bonuses to the most productive employees. Note that this scenario is conducted within the baseline scenario, in which education cost growth relative to wage growth increases from $\phi_{EC} = 1$ to $\phi_{EC} = 1.3$ from period $t = 201$ onward. Varying ϕ_B therefore allows us to assess whether different bonus distribution regimes amplify or mitigate the macroeconomic and distributional consequences of rising education costs. Given the baseline scenario with ϕ_B equal to 5, we vary the parameter from 0.9 to 10 and explore the impacts on inequality and overall economic dynamics (see Figure 5). Higher values of ϕ_B imply that bonuses increase more than proportionally with productivity, mimicking increasing returns to education or higher skill premiums (Goldin and Katz, 2018). When $\phi_B = 1$, bonuses are strictly proportional to productivity, while $\phi_B = 0.9$ represents a more egalitarian reward structure.

Figure 12 zooms in on the inequality indices across the various values of ϕ_B. As ϕ_B increases, the distributions of income and wealth become increasingly skewed, primarily due to rising incomes and wealth shares at the very top. In particular, higher values of ϕ_B mostly benefit the top 1%, while leaving the rest of the distribution largely unaffected (see Table 3). This concentration at the top explains why the Gini coefficients for income and wealth rise only moderately, even though the top 1% shares increase substantially. Indeed, the Gini index itself has limited sensitivity to changes in the upper tail of the distribution (Palma, 2014; Cobham et al., 2016), precisely where most of the inequality dynamics unfold in our simulations with high values of ϕ_B. In contrast, lowering ϕ_B below the baseline value of 5 markedly reduces inequality, as reflected in significantly lower income and wealth shares for the top groups and lower Gini coefficients overall.

Figure 12: Bonus distribution scenario - inequality indices

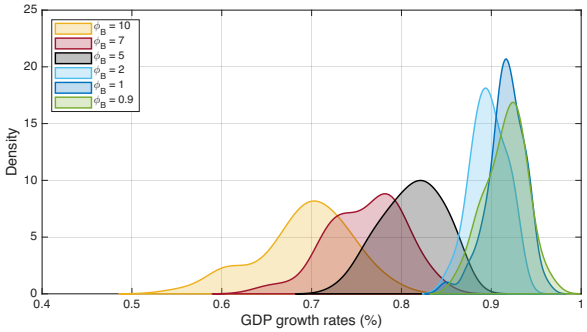


Notes: Share of income (top row) and wealth (bottom row) held by the top 1% (left panels) and top 10% (right panels) across experiments with varying bonus distribution parameter ϕ_B. Income share values are averages across 50 Monte Carlo runs over the indicated time spans, with error bars denoting one standard deviation. The baseline scenario corresponds to $\phi_B = 5$.

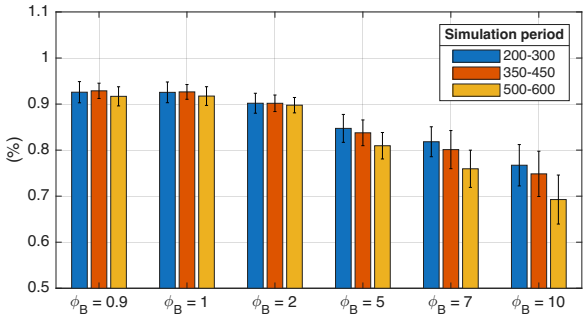
Figure 13 and Table 3 summarize the macroeconomic implications of varying the parameter ϕ_B. The left panel of Figure 13 shows that as inequality increases, the distribution of real GDP growth rates (computed over during the last 100 periods) shifts leftward and becomes wider, indicating both lower and more volatile growth outcomes. This is confirmed by the corresponding average growth rates across different time intervals depicted in the right panel. Also the summary statistics reported relative to the baseline in Table 3 show that more unequal bonus distributions

systematically weaken macroeconomic performance: average GDP and consumption growth fall to around 90–97% of the baseline for $\phi_B = 7$ and $\phi_B = 10$, while lowering ϕ_B to 1 or 2 raises growth by roughly 10–12%. Interestingly, in a more egalitarian system simulated with parameter value of $\phi_B = 0.9$, the economy performs just as well relative to the case of $\phi_B = 1$, in which workers are rewarded exactly according to their productivity. At the same time, inequality is further reduced. Hence, moving towards a less meritocratic remuneration structure does not come at the expense of macroeconomic performance. The underlying mechanism operates through the impact of inequality on households' access to education: the aggregate share of households with education drops to 74% and 66% of the baseline for $\phi_B = 7$ and $\phi_B = 10$, with the middle 40% particularly affected; the top 1% retains full access throughout, indicating that inequality primarily constrains education opportunities for lower and middle-income groups. Reduced access to education not only slows productivity growth, but weakens consumption demand, thus leading to higher unemployment rates, reflecting poorer coordination between labor demand and supply.

Figure 13: Bonus scenario - real GDP growth



(a) Distribution of average GDP growth between periods 500 and 600 for 50 MC runs across experiments with varying bonus parameters ϕ_B.



(b) Average real GDP growth across experiments with varying bonus distribution parameters. Values represent averages over 50 Monte Carlo runs for the indicated time spans, with error bars denoting one standard deviation. The baseline scenario corresponds to $\phi_B = 5$.

Overall, our simulations show that increasing returns to education, reflected in a higher skill premium, disproportionately benefit households that have already obtained education and remain able to invest in it, enabling them to capture a larger share of income and widen their advantage through continued investment in human capital. In turns, stronger concentration at the top reduces educational access for middle- and lower-income households, slowing human capital accumulation. This erosion of opportunity weakens aggregate demand and productivity growth, translating into lower and more volatile long-run GDP growth. Note that such puny macroeconomic performance emerges in presence of falling education costs, which are tied to the slower growth of average wage. Indeed, the rising compensation inequality dominates the reduction in education costs, reinforcing a self-perpetuating vicious cycle of lower access to education (Table 3), higher income inequality, weaker aggregate demand, and feebler productivity and output growth. This in turns points to the potential synergies between pre-distributive policies and other interventions to tackle income inequality.

Table 3: Bonus distribution scenario - summary statistics of key variables relative to the baseline

Variable	Baseline $\phi_B = 5$	Exp 1 $\phi_B = 0.9$	Exp 2 $\phi_B = 1$	Exp 3 $\phi_B = 2$	Exp 4 $\phi_B = 7$	Exp 5 $\phi_B = 10$
Macroeconomic variables						
GDP growth (%)	0.84	1.12***	1.12***	1.09***	0.97***	0.90***
Consumption growth (%)	0.84	1.09***	1.09***	1.06***	0.97***	0.91***
Avg. household productivity growth (%)	0.57	1.14***	1.14***	1.09***	0.97***	0.96***
Unemployment rate (%)	2.52	0.44***	0.44***	0.54***	1.32***	1.64***
Wage share (%)	62.27	1.00***	1.00***	1.00***	1.00	1.00**
Public debt/GDP (%)	74.11	0.98***	0.98***	0.98***	1.01***	1.03***
Education-related variables						
Education cost growth (%)	1.07	1.13***	1.12***	1.10***	0.94***	0.86***
Education share (%)	13.64	2.16***	2.13***	1.79***	0.74***	0.66***
Education share top 1 (%)	100.00	1.00	1.00	1.00	1.00	1.00***
Education share top 10 (%)	98.90	1.01***	1.01***	1.01***	0.80***	0.49***
Education share mid 40 (%)	9.21	5.26***	5.16***	3.92***	0.47***	0.77***
Education share bottom 50 (%)	0.13	0.40***	0.38***	0.21***	8.37***	20.81***
Inequality indices						
Gini Income	0.36	0.58***	0.61***	0.78***	1.04***	1.06***
Gini Wealth	0.72	0.71***	0.74***	0.86***	1.01***	1.01***
Income share top 1 (%)	18.58	0.14***	0.15***	0.31***	1.32***	1.57***
Income share top 10 (%)	37.71	0.49***	0.52***	0.70***	1.03***	1.05***
Income share mid 40 (%)	32.17	1.43***	1.42***	1.27***	0.97***	0.96***
Income share bottom 50 (%)	30.13	1.18***	1.16***	1.08***	0.99	0.98**
Wealth share top 1 (%)	31.68	0.14***	0.16***	0.32***	1.31***	1.55***
Wealth share top 10 (%)	63.51	0.52***	0.54***	0.72***	1.02***	1.02***
Wealth share mid 40 (%)	28.23	1.88***	1.85***	1.55***	0.93***	0.93***
Wealth share bottom 50 (%)	8.26	1.70***	1.61***	1.24***	1.04***	1.07***
Bonus share top 10 (%)	94.98	0.38***	0.41***	0.64***	1.03***	1.03***

Notes: For the baseline, values report the Monte Carlo average of each variable over periods 500–600. For the non-baseline scenarios, entries report the ratio of the Monte Carlo mean in the experiment to the Monte Carlo mean in the baseline. Significance stars indicate rejection of the null hypothesis of no difference from baseline: *** p<0.01, ** p<0.05, * p<0.10. Income shares are post-tax.

4.3.3 Combined scenario: Bonus distribution and education costs

The third scenario explores the combined effects of altering both the bonus payout structure and the education cost structure in order to investigate the interactions between these two critical dimensions and their combined impact on inequality and economic growth. More specifically, we consider nine combinations of the parameters ϕ_B and ϕ_{EC} (cf. the combined scenario in Figure 5).

Table 4 summarizes the simulation results focusing on the relationship between education costs, access to education, income inequality and output growth averaged over the last 100 periods for each of the nine parameter combinations outlined earlier. Our findings reveal the emergence of distinct economic regimes characterized by varying levels of inequality and growth which stems from the interplay of supply and demand factors.

When the bonus payout structure is highly skewed towards high skill workers (high ϕ_B) and education costs are high relative to wage growth (high ϕ_{EC}), the economy settle in a low-growth high-inequality trap (Table 4a and 4b). This scenario reflects a situation where only few individual can afford education (Table 4d) even though education costs are relatively low in

absolute levels due to slow wage growth (Table 4c), leading to an entrenched cycle of low growth and high inequality.

When education costs are low relative to wage growth (low ϕ_{EC}) but skill premium is high (high ϕ_B), the access to education broadens, increasing the share of households with education. However, inequality worsen with respect to the benchmark scenario, as households with initially higher productivity benefit disproportionately from the strongly skewed distribution of bonus compensations, allowing top-income households to consolidate their lead despite wider educational access. This pattern aligns with empirical and historical evidence showing that initial or inherited advantages can persist and shape long-run outcomes, even when access to economic opportunity expands (Piketty, 2014; Chetty et al., 2014). As a result, the benefits of broader educational access on growth remain limited as the high inequality undermines consumption (e.g., Fitoussi and Saraceno, 2010; Stiglitz, 2012).

Table 4: Combined scenario - summary statistics of key variables relative to the baseline

(a) **Real GDP growth**

	$\phi_B = 1$	$\phi_B = 5$	$\phi_B = 10$
$\phi_{EC} = 0.9$	1.53***	1.27***	1.06***
$\phi_{EC} = 1.3$	1.34***	1.00 (Baseline)	0.73***
$\phi_{EC} = 1.5$	1.18***	0.86***	0.62***

(b) **Income share of the top 10%**

	$\phi_B = 1$	$\phi_B = 5$	$\phi_B = 10$
$\phi_{EC} = 0.9$	0.48***	0.97***	1.04***
$\phi_{EC} = 1.3$	0.52***	1.00 (Baseline)	1.05***
$\phi_{EC} = 1.5$	0.56***	1.02***	1.05***

(c) **Education costs**

	$\phi_B = 1$	$\phi_B = 5$	$\phi_B = 10$
$\phi_{EC} = 0.9$	0.44***	0.38***	0.33***
$\phi_{EC} = 1.3$	1.43***	1.00 (Baseline)	0.67***
$\phi_{EC} = 1.5$	2.24***	1.45***	0.88***

(d) **Household share with education**

	$\phi_B = 1$	$\phi_B = 5$	$\phi_B = 10$
$\phi_{EC} = 0.9$	4.58***	4.14***	4.44***
$\phi_{EC} = 1.3$	2.13***	1.00 (Baseline)	0.66***
$\phi_{EC} = 1.5$	1.16***	0.60***	0.19***

Notes: Values represent Monte Carlo averages over the time span 500-600 relative to the baseline. Significance stars indicate rejection of the null hypothesis of no difference from baseline: *** p<0.01, ** p<0.05, * p<0.10.

Conversely, when bonuses are more evenly distributed (low ϕ_B), but education remains expensive with respect to wage growth (high ϕ_{EC}), we observe low inequality alongside moderate growth. In this case, the high cost of education limits human capital formation with resulting stagnating income growth along the whole distribution. This regime echoes the idea that redistribution without sufficient investment in education opportunity expansion may impede high growth.

Finally, when bonuses are distributed more equally (low ϕ_B) and education costs are low with respect to wage growth (low ϕ_{EC}), the economy enters into a high growth path characterized

by lower level of inequality. Such a result stems from the improved synchronization of the supply and demand channels, as the more abundant educational opportunities foster human capital formation, while the more egalitarian compensation of employees sustain consumption and in turns production. Policymakers should then jointly pursue equality of opportunities and equality of rewards (Stiglitz, 2012) to avoid that higher inequality levels undermine long-run growth (OECD, 2015; Berg and Ostry, 2017; Berg et al., 2018).

4.4 Education policy scenario

The last battery of simulations concerns an education policy scenario in which the government subsidizes education for households at the lower end of the wealth distribution. Specifically, the policy targets households that are eligible for education but lack financial resources to cover the current education cost. Among this group of financially constrained households, the government fully subsidizes education for the poorest $x\%$, with $x \in 10, 25, 50$.[16]

Such polices are motivated by the observation that access to education is often constrained not only by ability or eligibility, but also by households' financial resources. Rising education costs, combined with unequal income and wealth distributions, can prevent otherwise eligible individuals from obtaining in education, thereby limiting human capital accumulation and reinforcing intergenerational inequality. The policy therefore aims to relax these liquidity constraints by subsidizing education for financially constrained households and to assess the extent to which financial barriers contribute to persistent inequalities in educational attainment and macroeconomic outcomes.

The results of the subsidized education policy reveal substantial macroeconomic and distributional effects (Table 5). *First*, GDP and productivity growth increases across all subsidy levels and becomes more pronounced as policy coverage expands. The positive macroeconomic effects of the subsidy arise through both a demand and a supply channel. First, subsidized households retain a larger share of their income, which in turns increases aggregate demand. Second, lower financial barriers increase educational attainment and thereby raise productivity and potential output. These findings reveals the interplay of demand and supply factor which boost both output and potential output once the educational constraints for disadvantaged households are relaxed, thus producing aggregate benefits that extend well beyond the direct recipients of the subsidy.

Second, the subsidy shifts part of the cost of education from households to the government. This moderately increases the deficit-to-GDP ratio as the coverage of the subsidy expands (Table 5). However, the public debt-to-GDP ratio remains unaffected. This suggests that the initial cost of the education policy is offset by higher economic growth, which in turns expands the tax base through stronger output growth and employment.

Third, the policy substantially alters the distribution of educational opportunities. Overall access to education increases with the generosity of the subsidy. However, this effect is not

[16]Note that the policy scenario is conducted within the baseline scenario, in which the bonus distribution parameter is set to $\phi_B = 5$ and the education cost parameter increases from $\phi_{EC} = 1$ to $\phi_{EC} = 1.3$ from period $t = 201$ onward.

fully sustained over time: in all scenarios, overall educational attainment gradually declines. This reflects rising education costs relative to wages, which outpaces the expansionary effect of the subsidy over the long run. A more granular view by income group (Figure 14) highlights important compositional changes. The top income group maintains near-universal access to education across all scenarios. By contrast, the bottom 50% experiences a first a strong increase in access and is able to sustain its higher level of educational access, while access among the middle 40% declines persistently.

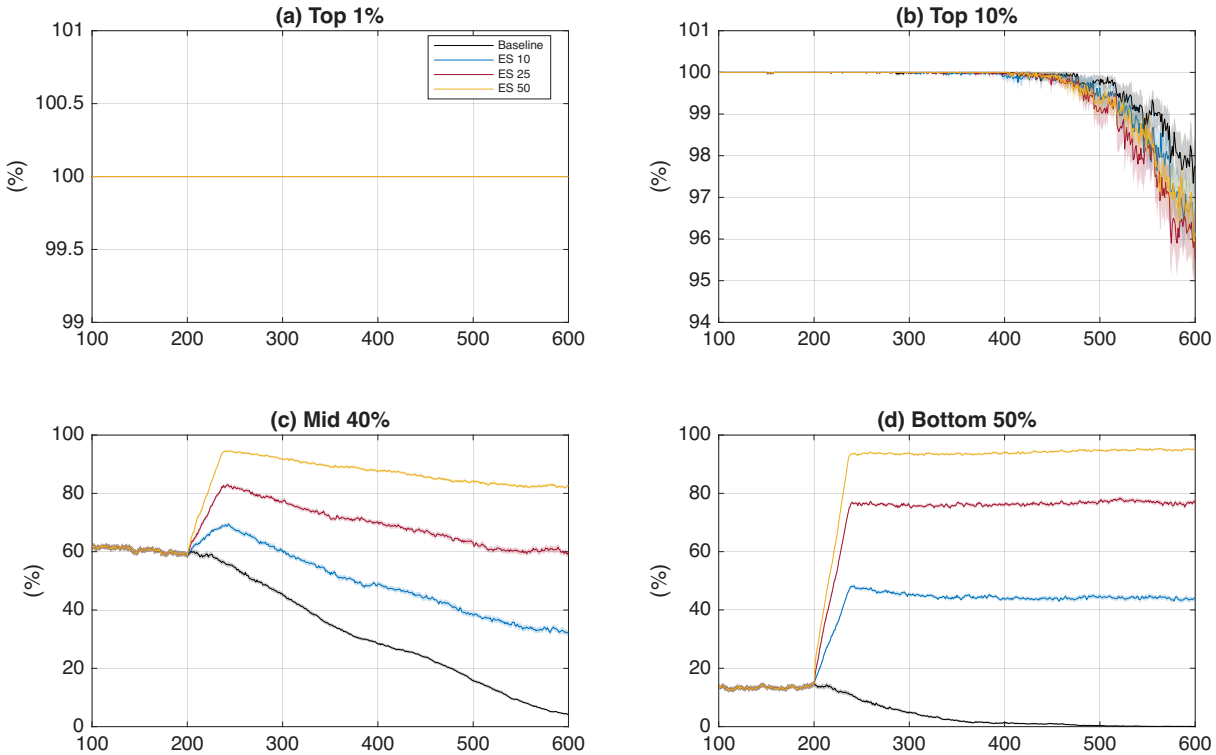
Fourth, these changes translate into moderate but systematic improvements in the distributional outcomes. When looking at the shares accrued by different income groups, we see that this effect is not driven by changes at the top: the income share of the top 10% remains effectively unchanged across all scenarios. Instead, the redistribution occurs mainly between the middle and lower parts of the distribution. Specifically, income shares shift from the middle 40% toward the bottom 50%, indicating partial catch-up dynamics rather than compression at the top end of the distribution. Overall inequality declines only slowly because bonus payments remain highly concentrated among top-income households, whose continued access to education allows them to retain most bonus income. The observed reduction in inequality therefore stems primarily from a narrowing gap between the bottom 50% and the middle 40%, as more equal educational opportunities enable lower-income households to improve their productivity and income shares.

Table 5: Education policy scenario - summary statistics of key variables relative to the baseline

Variable	Baseline No subsidy	Exp 1 Subsidy 10%	Exp 2 Subsidy 25%	Exp 3 Subsidy 50%
Macroeconomic variables				
GDP growth (%)	0.84	1.03***	1.10***	1.16***
Consumption growth (%)	0.84	1.03***	1.09***	1.16***
Avg. household productivity growth (%)	0.57	1.28***	1.52***	1.68***
Unemployment rate (%)	2.52	0.99	0.91***	0.84***
Wage share (%)	62.27	1.00	1.00**	1.00***
Public debt/GDP (%)	74.11	1.00	1.00***	1.00***
Public deficit/GDP (%)	0.60	1.05***	1.11***	1.18***
Education-related variables				
Education cost growth (%)	1.07	1.04***	1.09***	1.17***
Education share (%)	13.64	3.36***	5.32***	6.63***
Education share top 1 (%)	100.00	1.00	1.00	1.00
Education share top 10 (%)	98.90	0.99***	0.99***	0.99***
Education share mid 40 (%)	9.21	3.79***	6.59***	9.00***
Education share bottom 50 (%)	0.13	347.77***	607.53***	748.27***
Inequality indices				
Income share top 1 (%)	18.58	1.01	1.01	1.00
Income share top 10 (%)	37.71	1.00	1.00	0.99***
Income share mid 40 (%)	32.17	0.98***	0.97***	0.97***
Income share bottom 50 (%)	30.13	1.02***	1.04***	1.05***
Wealth share top 1 (%)	31.68	1.01	1.02	1.00
Wealth share top 10 (%)	63.51	1.00***	1.00***	1.00***
Wealth share mid 40 (%)	28.23	0.98***	0.97***	0.98***
Wealth share bottom 50 (%)	8.26	1.05***	1.08***	1.09***
Bonus share top 10 (%)	94.98	1.00***	1.00**	0.99***

Notes: For the baseline, values report the Monte Carlo average of each variable over periods 500–600. For the non-baseline scenarios, entries report the ratio of the Monte Carlo mean in the experiment to the Monte Carlo mean in the baseline. Significance stars indicate rejection of the null hypothesis of no difference from baseline: *** p<0.01, ** p<0.05, * p<0.10. Income shares are post-tax.

Figure 14: Education policy scenario - Share of households with education by income group for different values of the education subsidy (ES).



Notes: Top 1% (a), top 10% (b), mid 40% (c), bottom 50% (d). Values refer to 50 MC averages with shaded 95% confidence bands.

5 Conclusions

This paper develops an agent-based model (ABM) to study the relationship between education, inequality and macroeconomic dynamics focusing on meritocracy. While meritocracy is often perceived as a reward-based source of economic growth, it can amplify existing inequalities when access to education depends on unevenly distributed resources (Markovits, 2019; Sandel, 2020). By incorporating educational disparities and workers' compensation schemes grounded on individual productivity into an ABM, our study offers new insights into how meritocracy-driven inequality can perpetuate across generations, possibly affecting long-run macroeconomic outcomes.

Our simulation results show that unequal access to education not only exacerbates personal income and wealth inequality but also slows down productivity and long-term economic growth. Indeed, in presence of a surge in education costs, the reduced access to education constrains human capital accumulation for lower-income households, reducing upward mobility while concentrating income gains at the top. These distributional dynamics weaken consumption and reduce expenditures in productivity-enhancing education, thereby dampening long-run growth via both demand- and supply-side channels. The fall in the growth potential of the economy does not immediately follow the surge in the education costs, but it gradually unfolds over time. This warns against the long-run costs of a possible mismatch between inequality and educational

opportunities.

We then explore the possible interplay between education costs and the productivity-based rewards paid to the workers. We identify four distinct economic regimes. When both workers' bonuses are highly sensitive to individual productivity and education is costly, the economy is characterized by low growth and high inequality, with limited access to education exacerbating income disparities. In contrast, reducing education costs in a skewed employee's compensation framework increases access to education but fails to fully counterbalance the negative effects of inequality, leading to moderate growth with persistent high inequality. When workers' bonuses are less sensitive to individual productivity differentials, but education remains expensive, we observe low inequality, but also low growth due to constrained human capital development. Finally, the most favorable regime, with low inequality and high growth, emerges when employee's bonuses are equitably distributed and education is affordable, promoting widespread access to education and higher consumption. These findings highlight the substantial economic costs of meritocratic compensation schemes in the presence of unequal access to education. This is consistent with the empirical literature showing that high level of inequality can slow down growth and emphasizes access to education as a key channel (e.g., OECD, 2015; Berg and Ostry, 2017; Berg et al., 2018). In contrast, a more egalitarian compensation system can reduce inequality without sacrificing macroeconomic performance.

Finally, we study the impact of an education policy in which the government subsidizes education for the possible financially-constrained households at the lower end of the wealth distribution. Simulation results show that such a policy intervention boosts GDP growth as higher educational access increases both firm productivity and households consumption. These positive results are achieved without increasing the long-run fiscal burden as the policy is able to spur tax revenues via higher economic growth. The education policy is also able to tackle inequality by increasing the income share obtained by the bottom 50% of the income distribution. Our results underscore the potential effectiveness of pre-distributive policies in taming inequality (Blanchet et al., 2022; Bozio et al., 2024) while spurring growth.

Our research could be extended along different complementary avenues. First, one could further explore the impact of different types of educational policies, possibly introducing an explicit education sector into the model. Additionally, educational policies could be paired with fiscal redistributive measures, such as progressive income taxes, wealth taxes, and inheritance taxes. Finally, incorporating household debt into the model could provide a more comprehensive understanding of the financial (in)stability implications of student debt and the broader consequences of meritocracy-driven inequality.

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A Parameter values

Table A1: Baseline parametrization of the model

Symbol	Value	Description
λ	0.5	Adaptive expectations parameter
mu	0.6	Pricing mark-up
ι	0.1	Desired inventories as a share of expected sales
ϕ_B	5	Bonus distribution parameter (baseline)
ϕ_{EC}	1.0/1.3	Education cost parameter (baseline)
μ_1	0.005	Expected value for households without education
μ_2	0.015	Max. expected value for households with education
σ	0.005	Standard deviation (technological progress)
c_v	0.3	Propensity to consume out of wealth
τ_b	0.21	Tax rate on bonuses
τ_p	0.21	Tax rate on profits
ω	0.4	Unemployment benefits as a share of average wage rate
ltv_f	1.5	Loan-to-value for firm credit
CAR	0.08	Capital requirement
r_l	0.03	Interest rate on loans
r_d	0.0	Interest rate on deposits

Table A2: Household parameters by income decile

Income decile	Propensity to consume	Wage tax rate
1	1.00	0.15
2	1.00	0.15
3	0.95	0.15
4	0.90	0.15
5	0.85	0.15
6	0.80	0.25
7	0.75	0.25
8	0.70	0.25
9	0.60	0.25
10	0.50	0.35

Notes: Average propensities to consume (APC) are by disposable income decile and wage tax rates by wage income decile.

B Productivity dynamics

Each household $n \in \{1, \ldots, N\}$ is characterized by an individual productivity level $A_{n,t}$, which evolves according to the multiplicative process in Eq 2:

$$A_{n,t} = A_{n,t-1}(1 + \delta_{n,t}), \tag{B1}$$

where $\delta_{n,t}$ denotes the household-specific productivity growth rate.

Aggregate household productivity is defined as the average productivity level across all households (Eq. 32):

$$A_t^N = \frac{1}{N} \sum_{n=1}^{N} A_{n,t}. \tag{B2}$$

The associated aggregate productivity growth rate is therefore

$$g_{A,t} = \frac{A_t^N - A_{t-1}^N}{A_{t-1}^N}. \tag{B3}$$

This measure captures the growth rate of the aggregate productivity level in the economy. At the micro level, each household experiences an individual productivity growth rate given by

$$g_{A_{n,t}} = \frac{A_{n,t} - A_{n,t-1}}{A_{n,t-1}} = \delta_{n,t}. \tag{B4}$$

The average of individual growth rates is:

$$g_{\bar{A}_{n,t}} = \frac{1}{N} \sum_{n=1}^{N} g_{A_{n,t}}. \tag{B5}$$

In general, aggregate productivity growth differs from the average of individual growth rates ($g_{A_t} \neq g_{\bar{A}_{n,t}}$). Instead, aggregate productivity growth can be expressed as a productivity-weighted average of individual growth rates:

$$g_{A,t} = \sum_{n=1}^{N} \omega_{n,t-1} \delta_{n,t}, \tag{B6}$$

where

$$\omega_{n,t-1} = \frac{A_{n,t-1}}{\sum_{m=1}^{N} A_{m,t-1}} \tag{B7}$$

denotes household n's share of aggregate productivity in period $t-1$.

The difference between aggregate growth and the mean of individual growth rates arises from heterogeneity in productivity levels. Households with higher productivity contribute more strongly to the aggregate measure. Therefore, even if the unweighted mean of individual growth rates $g_{\bar{A}_{n,t}}$ declines over time, aggregate productivity growth $g_{A,t}$ may remain stable if productivity growth is concentrated among highly productive households. This highlights that aggregate productivity dynamics are shaped not only by individual growth processes but also by the distribution of productivity across households.

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