Concentration, Stagnation and Inequality: An Agent-Based Approach*

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Abstract

This paper analyzes the underlying causes of the recent increase in market concentration, by focusing on the interplay of technical change and market power, and how this relates with income inequality and secular stagnation. We do this by developing a macro agent-based model with endogenous technical change and heterogeneous vintages of machine tools, whose built-in productivity depends on a stochastic innovation process. The source of concentration lies in the fact that heterogeneous firms do not have equal access to capital-embodied innovations, as we assume that this depends on the "knowledge gap", i.e., the difference between the degree of capital good's technical advancement and the firm's accumulated technological knowledge. The analysis shows that, in the absence of consistent knowledge spillovers and as long as capital goods remain considerably different from each other, technical progress generates systematic divergence in productivity across firms, leading to a reallocation of market shares towards more productive firms. Moreover, as the newly-emerging large firms seek to translate the enhanced market power into higher mark-ups, the resulting shift in the income distribution from wages to profits eventually undermines aggregate demand and growth. Yet, simulation experiments reveal that, in the absence of legal entry barriers, the imitation activity by capital good firms brings about a convergence among different techniques, which, by reducing technological discontinuities, creates the conditions for a competitive and self-sustained growth process.

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1 Introduction

Over the last three decades, advanced economies, particularly the U.S., have undergone major structural changes which manifest themselves in a number of secular trends, i.e., rising market concentration, widening income inequality and secular stagnation.

Since the early 1990s, more than 75% of U.S. industries have witnessed rising concentration levels, as measured by the Herfindahl-Hirschman (HH) index, which grew on average by 90% (Grullon et al., 2019). Moreover, many studies have documented a widespread increase in income inequality, especially among western countries, both in the functional and personal distribution (Stiglitz, 2012; Piketty, 2014; Karabarbounis and Neiman, 2014; Atkinson, 2015). More recently, empirical research has made attempts to identify potential links between changes in market structure and income distribution. Barkai (2020), for instance, highlight that firms operating in more concentrated industries have experienced extraordinary high profit rates. This evidence opened a debate, mostly empirical, on the causes and consequences of market concentration. Whilst Autor et al. (2017, 2020) emphasize the role of technical change and productivity gains in enabling superstar firms to achieve a larger market share with less labor, Grullon et al. (2019) and De Loecker et al. (2020) suggest that the rise in corporate profits is mainly driven by increasing profit margins due to market power and entry barriers rather than improvements in operational efficiency. De Loecker et al. (2020), in particular, find that in the U.S. economy mark-ups remained roughly constant between 1950-1980 and, from then on, have grown steadily, with the average price going from 21% to 61% above marginal cost. Against this background, some authors have stressed that, despite historically low interest rates, increasing profitability and high funds availability, the investment rate of U.S. non-financial corporations has been constantly slowing down, from 32% in the 1980s to 26% in the 2010s (Gutiérrez and Philippon, 2016; Villani, 2021). According to Gutiérrez and Philippon (2017), such an "investment gap" is stronger in concentrating industries, where, in view of diminishing profitable investment outlets, monopolistic rents are largely distributed to shareholders by means of dividend payments and share buybacks (Gutiérrez and Philippon, 2016, 2017; Turco, 2018). The slowdown of capital accumulation is then reflected in the long-lasting decline in average output growth, which decreased from 3.7% between 1947-1980 to 2.7% between 1980-2017 (Stiglitz, 2019).

Although recent empirical research has made an effort to document and emphasize the potential connections among these trends (Syverson, 2019), in our view, a comprehensive theoretical framework is yet to be developed.

The present paper aims to contribute to filling this gap, by proposing a theoretical framework that allows to systematically analyze the endogenous formation and dynamic interdependence between changes in market structure, income distribution and economic growth. In particular, the aim of this paper is threefold: (i) to develop a macroeconomic agent-based model (ABM) in order to examine the causes and consequences of rising market concentration, by focusing on the interplay of technical change and market power; (ii) to explore, by means of computer simulations, the conditions under which the tendency to concentration at the micro level may give rise to a tendency to stagnation at the macro level; (iii) to implement a variety of policy experiments in order to assess the role of different institutional setups, e.g. entry barriers, and identify the best policy mix able to curb the stagnation tendency and to foster a competitive and innovation-led growth process.

1.1 Theoretical roots

To explain the endogenous formation and the dynamic interdependence among the secular trends characterizing modern advanced economies, that is, concentration, stagnation and inequality

(Stiglitz, 2019; Syverson, 2019; De Loecker et al., 2020), we propose a narrative that combines old and new findings from the micro- and macro-economic literature on oligopoly, technical change, distribution and growth, and, on top of that, introduces some novel features.

First of all, we resume and revise Sylos Labini's (1967) theory of oligopoly and technical progress, according to which the tendency to concentration is driven by technical change that generates "technological discontinuities", i.e., systematic differences in productivity across firms, leading to a reallocation of market shares towards more productive firms. This is because heterogeneous firms do not have equal access to capital-embodied innovations, as we assume that this depends on the "knowledge gap", i.e., the difference between the degree of capital vintage's technical advancement and firm's level of technological knowledge. Based on Cohen and Levinthal (1989), we explicitly formalize a process of knowledge accumulation, whose function is to improve firms' ability to identify, assimilate and master the best machines developed by capital good producers. By influencing the firms' access to capital-embodied innovations, the knowledge stock, accumulated over time through R&D, constitutes a form of technical barrier to entry, or rather *to use* (Dosi and Nelson, 2010), which underlies the growing divergence in productivity and competitiveness across firms. It follows that, *in the absence of* consistent knowledge spillovers and *as long as* capital goods remain considerably different from each other, the intertwined dynamics of knowledge accumulation and technical change is the driver of the endogenous formation of firms' heterogeneity and technical entry barriers, paving the way for a shift in the market structure from a competitive to an oligopolistic form.

The theoretical link between the microeconomic analysis of oligopoly and technical progress and the macroeconomic analysis of income distribution and growth passes through the changing pricing behavior by the large newly-emerging firms.

In a competitive economy, because of low entry barriers and limited market power, firms act as *price taker* units, i.e., the price converges to the marginal cost. In such a context, the falling unit labor cost stemming from technical change translates into lower output prices and subsequently higher real incomes, providing the basis for a self-sustained growth process. At this stage, a rise in concentration due to, for instance, an increased market competition may in fact imply a higher productivity growth and better economic performance, as argued by Autor et al. (2020).

However, the shift towards an oligopolistic market form following the emergence of technical entry barriers implies that large firms end up with a considerable degree of market power, thus becoming *price maker*. In the absence of a competitive pressure, the price is not taken as given, but is set endogenously by firms, who apply a mark-up over unit labor cost according to their 'degree of monopoly power', as reflected in the individual market share (Kalecki, 1942). Operating under conditions of oligopoly characterized by technical entry barriers, large firms seek to translate the enhanced market power into higher profit margins. Consequently, as the influence of large firms grows over the economy, the rise in the weighted-average mark-up leads to a shift in the income distribution from wages to profits that eventually undermines consumption and aggregate demand (Keynes, 1936), with detrimental effects on investment and long-run growth. As a result, in the absence of countervailing forces, the tendency to concentration at the micro level may give rise to a tendency to stagnation at the macro level.[1]

1.2 The formal model: key features and properties

We formalize this framework and further explore its dynamic properties by means of an agent-based macroeconomic model. From a methodological point of view, we believe that an ABM is

[1] Baran and Sweezy (1966), Sylos Labini (1967) and Steindl (1976) previously reached similar conclusions, albeit from different perspectives.

the most appropriate tool to address our research question. Indeed, we exploit the granularity of the agent-based approach to study the endogenous evolution of firms' heterogeneity underlying the emergent dynamics of concentration, without resorting to different initial conditions across firms and/or exogenous shocks to the parameters of the model. By contrast, similar studies based on a (heterogeneous agent) New Keynesian framework, such as Autor et al (2017), require firms to be initially endowed with different productivity levels. Moreover, the rise in concentration occurs through an exogenous change that allocates more market share to more productive firms, e.g. an increase in consumers sensitivity to prices. In our model, such a reallocation mechanism is endogenous to the model dynamics and results from the firms' choice of heterogeneous capital vintages in a decentralized capital goods market. This allows us not only to describe the effects of rising concentration on the economic system but also to explain the forces behind it.

In line with the macro-evolutionary tradition, our model is characterized by endogenous technical change and heterogeneous capital goods, whose built-in productivity depends on a stochastic innovation process. Yet, differently from other ABMs in this literature where the innovation activity is carried out exclusively by capital good firms (K-firms hereafter) to search for new innovations and to imitate that of competitors (Dosi et al., 2010; Dawid et al., 2019; Caiani et al., 2019), in our model also consumption good firms (C-firms) can invest in R&D in order to accumulate technological knowledge, which allows them to identify and employ the best techniques produced by K-firms. Following Cohen and Levinthal (1989), technological knowledge can either be generated internally by means of firms' own R&D or externally by absorbing knowledge spillovers coming from other firms. The knowledge stock, in turn, affects the firms' choice of capital vintages, which depends on the "knowledge gap", i.e., the difference between the degree of capital good's technical advancement and firm's accumulated technological knowledge. Therefore, throughout the process of capital accumulation, firms with greater technological knowledge are more likely to adopt more efficient machines, thus achieving faster productivity gains.

The remaining part of the model incorporates the following features: the households sector consists of workers and firm owners, who earn labor and capital income, respectively, and consume a homogeneous good produced by C-firms using labor and heterogeneous capital; a representative bank collects deposits from households and firms and supplies credit to borrowing firms; the Government levies taxes on wages and dividends and distributes unemployment subsidies to non-working individuals. Despite starting with the same initial conditions, households and firms become heterogeneous over time by virtue of the casual interactions in decentralized labor, consumption and capital good markets.

The model is able to reproduce the intertwined stylized facts of concentration, stagnation and inequality. These dynamics emerges 'from the bottom up', as a result of the adaptive behavior of heterogeneous agents interacting in decentralized markets. In the jargon of complexity theory, they are *emergent properties* of the system.

In particular, after a short period of transition, the model endogenously generates a wave of market concentration driven by technical change, which leads to a reallocation of market shares towards more productive and knowledge-intensive firms. Afterwards, large firms tend to exert their enhanced market power to raise mark-ups. The ensuing slowdown in real wages determines a shortage in aggregate demand, on the one hand, and excess capacity, on the other. As a result, firms cope with the lower demand by reducing the utilization rate of the existing plants without investing in new capital formation, net of depreciation, with negative effects on output and productivity growth. Therefore, the economic system spontaneously reaches a state of stagnation as a consequence of changes in market structure and income distribution, triggered by technical progress and market power.

However, by comparing two alternative scenarios corresponding to different patent system regulations, we find that, when K-firms are allowed to imitate their competitors' technologies, market competition is soon re-established. This is because the imitation activity carried out by K-firms brings about a convergence amongst different techniques, which, by reducing technological discontinuities in the consumption sector, allows laggards to catch up. Conversely, in the "no-imitation" scenario, the persistent heterogeneity among capital goods is then reflected in the systematic divergence in productivity across C-firms. In such a scenario, in so far as legal entry barriers reinforce technological discontinuities, large firms are able to consolidate their dominant position and to extract a higher share of rents, with harmful effects on distribution, demand and growth also in the long run.

Therefore, from our simulation analysis it emerges that, whereas the initial wave of concentration is triggered by knowledge-based technical entry barriers, which constrain firms' access to capital-embodied innovations, the evolution of concentration over time crucially depends on the presence (or lack thereof) of legal entry barriers, which affects the process of diffusion of technological innovations and thus firms' ability to consolidate their position and to exploit their market power. More generally, our findings suggest that the pattern of economic growth is driven by the dynamic interrelationship between technological evolution in the capital sector and market power in the consumption sector, with following non-trivial effects on income distribution and aggregate demand.

Furthermore, we perform a battery of policy experiments, such as competition, innovation, fiscal and labor market policies, in order to identify the best policy mix able to halt the stagnation tendency and to foster a competitive and innovation-led growth process.

We find that labor market reforms aimed at weakening labor unions, by boosting profit margins and innovation, can foster a profit-led growth. This comes from the assumption that R&D is a function of realized profits – instead of sales, as in Dosi et al. (2010) –, which makes the relationship between innovation, growth and distribution less trivial. Yet, the following slowdown in wages and demand needs be compensated by an anti-cyclical fiscal policy, without which the economy would remain stuck in a high unemployment-low growth trap. Moreover, while in the absence of entry barriers a reduction of transaction costs may promote a competition-driven concentration which benefits growth, innovation policies geared to spurring knowledge spillovers across firms risk to be ineffective as long as the technical ability to process them remains unequally distributed in a concentrated industry. Finally, a restrictive fiscal policy that prevents a fully anti-cyclical management of the public budget accentuates the stagnation tendency which eventually results in higher concentration, as the reduced demand is largely satisfied by a lower number of firms.

1.3 Existing literature

The present work provides a contribution to three streams of literature.

First of all, this paper belongs to the increasing body of literature on macroeconomic agent-based models, of which Dawid and Delli Gatti (2018) provide an extensive review. In particular, our model builds upon Assenza et al. (2015), who develop a macro ABM in order to investigate how the interaction between firms of different sectors and the evolution of their financial conditions lead to the emergence of recurrent economic crises. Moreover, we incorporate features from macro-evolutionary ABMs, such as Dosi et al. (2010), Caiani et al. (2019) and Dawid et al. (2019), where technical progress is driven by stochastic innovations introduced in the economy by heterogeneous capital good firms. Macroeconomic agent-based models have been employed to study various complex economic phenomena as well as to address a wide range of policy questions. Narrowing the focus on the issues discussed in this paper, while there are numerous studies on inequality (e.g. Dosi et al., 2013; Russo et al., 2016; Dawid et al., 2018; Dosi et al., 2018; Cardaci, 2018; Caiani et al., 2019) and, to a lesser extent, on large-scale economic downturn (e.g. Giri et al., 2019), the causes and consequences of rising market concentration, especially in relation with income inequality and economic stagnation, are less investigated in the macro ABM literature. Hepp (2021) studies the emergence of superstar firms and finds which corporate features are able to predict the success of firms. Dawid et al. (2021) examine the impact of different degrees of centralization of the wage setting process on concentration and inequality, showing that higher centralization determines lower wage inequality and higher concentration on the consumption goods market. While these papers are close in spirit to ours, the analysis presented here provides an alternative explanation for the process of rising concentration and its implications, based on the role of firms' accumulation of technical knowledge and increased market shares as source of market power.

Secondly, this paper contributes to the ongoing debate on the causes and consequences of market concentration. In the current literature, mostly empirical, it is possible to identify two alternative hypotheses that we will label as "efficiency-enhancing" and "rent-extracting" concentration hypotheses. According to the *efficiency-enhancing hypothesis*, market concentration is the outcome of technical change spurred by the adoption of more efficient techniques by large ("superstar") firms (Autor et al., 2020). By exploiting scales economies and low unitary costs, those firms are able to sustain big upfront innovative investment, hence achieving productivity gains, cost reductions and larger market shares. Therefore, rising concentration, by improving the efficient allocation of resources and fostering aggregate productivity, has a positive impact on the economy, although it may come at the cost of a lower wage share following the introduction of labor-saving innovations (Autor et al., 2017).

On the other hand, according to the *rent-extracting hypothesis*, market concentration is associated with the enhanced market power resulting from higher entry barriers, either legal or technological, which undermine competition by preventing potential rivals from entering the market (Grullon et al., 2019; Barkai, 2020; De Loecker et al., 2020). The enhanced market power is then reflected in higher mark-ups, leading to a shift in the income distribution from wages to profits. From a macroeconomic perspective, a falling labor share determines a decline in aggregate consumption because "those at the top have lower propensity to consume than those at the bottom" (Stiglitz, 2019). Moreover, due to the lack of competitive threats, firms operating in concentrated industries might have less incentives to innovate, while patent protections may restrict laggards' possibility to imitate, with this resulting in lower investment (Decker et al., 2016; Gutiérrez and Philippon, 2019). As a result, the process of market concentration, by exacerbating income inequality and weakening aggregate demand, is detrimental to economic growth.

In their work on intangible capital and concentration, Crouzet and Eberly (2019) put forward a third interpretation, based on the idea that the two aforementioned hypotheses, rather than mutually exclusive, can be regarded as two alternative equally-likely scenarios that arise depending on the sources of rising concentration. In this view, concentration might be "good", if triggered by productivity-enhancing technological innovations, or "bad", if due to entry barriers giving rise to market power.[2] Using U.S. firm and industry level data between 1988-2015, the authors find mixed, sector-specific evidence on the impact of rising concentration on business investment and economic performance, claiming that this would provide support to their thesis.

Like Crouzet and Eberly (2019), we are reluctant to consider the two above mentioned hypotheses as mutually exclusive. Rather, by adopting a complex approach, we interpret them as distinct outcomes that may possibly emerge out of the dynamic interaction between technical change and market power, and their relationship with the changing institutional environment. To

[2] "The source of rising concentration is thus important for understanding the extent to which rising concentration is efficient or not, and possible policy implications" (Crouzet and Eberly, 2019).

put it differently, in our framework the effects of concentration are not necessarily pre-determined by its sources, as in Crouzet and Eberly (2019). It is possible that rising concentration, even if triggered by technical change, may eventually have detrimental effects on the economy as long as large firms manage to exploit their enhanced market power resulting from the establishment of (technical or legal) entry barriers. On the other hand, if imitation activity is allowed, a higher product market competition may actually foster a positive concentration – see policy experiments –, because, in the absence of legal entry barriers, large firms would not be able to consolidate their position and extract monopolistic rents.

Thirdly, by the way in which the firm's choice of capital vintages is formalized, this paper creates a bridge between the macro and the micro/industrial evolutionary literature of innovation and technical change. In the macro-evolutionary literature (Dosi et al., 2010; Caiani et al., 2019), in fact, the corporate sector is made of consumption good firms and capital good firms whereby the former buy machine tools from the latter based on their relative price, which is inversely proportional to the respective productivity. This means that, quite oddly, the most efficient machines are also the cheapest ones, thereby everyone can easily access them. Many contributions in the micro-evolutionary literature, instead, stress the role of technological knowledge in the success of innovative activities carried out by (capital good) firms (Cantner and Pyka, 1998; Cohen and Levinthal, 1989; Dawid, 2006). This paper proposes a synthesis of the two approaches by conceiving technological knowledge as a means to improve the C-firms' ability to employ the best machines produced by K-firms. As such, the knowledge stock has a similar function as the average skill level of workers in the EURACE model (Dawid et al., 2019), where the firm's choice of a capital vintage depends upon the current expectation of its effective productivity, which, in turn, may be possibly constrained by the workers' accumulated capabilities. In this regard, the main difference with the EURACE model is that while in Dawid et al. (2019) technological knowledge is embedded in the skill level of workers, we put forward an explicit formalization of the process of knowledge accumulation, which evolves over time by means of R&D carried out by research workers, in tune with Cohen and Levinthal (1989).

2 Model setup

The model is characterized by (i) a corporate sector, including N capital good producers (or *innovators*) and F consumption good producers (or *entrepreneurs*); (ii) a household sector, composed of W workers and $K = N + F$ capitalists, i.e., there is one owner per firm; (iii) a banking sector with one representative bank; (iv) a public sector, namely the Government.

The structure of the model builds upon the macro agent-based model with capital and credit (CC-MABM) developed by Assenza et al. (2015). A few major changes are introduced with respect to the parental model: (i) entrepreneurs' quantity and price decisions are taken separately, being the former based on expected sales, while the latter on the degree of market power; (ii) capital goods are heterogeneous with respect to built-in productivity, whose improvements depend upon a stochastic innovation process à la Dosi et al. (2010); (iii) C-firms also perform R&D in order to accumulate technological knowledge, which enhances their ability to identify and employ the best machines produced by innovators.

Coherent with Assenza et al. (2015), workers and firms are heterogeneous agents and interact in decentralized labor, consumption and capital goods markets. In the labor and C-good markets, the interaction occurs via the search-and-matching mechanism (Riccetti et al., 2015), while the choice of the capital vintage is determined by a logit model, similarly to Dawid et al. (2019). Because of transaction costs, markets are incomplete and coordination issues may arise. In the absence of a centralized market-clearing mechanism, the system may self-organize towards a spontaneous order characterized by sub-optimal outcomes and out-of-equilibrium dynamics.

2.1 Sequence of events

Over a period of the simulation run, events unfold in the following order:

1. *Production planning and factors demand:* Based on expected sales, C-firms compute desired production, utilization rate and labor demand for both production and research workers.
2. *Capital goods market (1):* C-firms select their potential supplier of machine tools depending on the 'knowledge gap', which measures the distance between capital goods' technical advancement and C-firms' level of technological knowledge.
3. *Credit market:* If production costs exceed internal funds, C-firms resort to the bank asking for a loan.
4. *Labor market:* Firms can hire and fire production and research workers according to their labor requirements; employees receive a wage.
5. *Production and price:* C-firms' production is computed as the minimum between desired and potential output, given the available resources; the price is set by charging a mark-up over the unit labor cost depending on the firm's degree of market power.
6. *Capital goods market (2):* Entrepreneurs with a positive investment demand buy the required capital units from the previously selected supplier. Capital goods, produced by innovators according to a Make-to-Order plan, are made available for the production process starting from next period.
7. *R&D activity (1):* Both consumption and capital good firms implement R&D activity based on previously allocated funds: C-firms update their knowledge stock; K-firms perform innovation and imitation activities to develop more efficient vintages of capital goods.
8. *Taxes and subsidies:* Government collects taxes on wages and dividends and distributes unemployment benefits to non-working individuals.
9. *Consumption goods market:* Having defined their consumption budget, households visit a given number of firms and choose the supplier after comparing their selling prices.
10. *Profits and dividends:* Firms collect revenues and distribute part of their profits to capitalists as dividends, on which the Government collects taxes.
11. *R&D activity (2):* Both consumption and capital good firms allocate part of realized profits to the R&D budget that will be invested in the following period.
12. *Entry-exit dynamics:* Retained earnings accumulate to net worth. If the equity turns negative or liquidity is not enough to repay interests and debt installment, firms declare default. Bankrupted firms exit and are re-capitalized by means of the owner's wealth.
13. *Public deficit and bond issuance:* The Government issues bonds, purchased by the bank, to finance the public expenditure in excess of tax revenues; public debt is updated accordingly.
14. *Bank's profits, dividends and equity:* The bank collects interest payments from borrowings, records non-performing loans and distributes dividends to capitalists; after-dividends earnings pile up to the bank's equity. If the latter turns negative, all households participate to the bail-in proportionally to the scale of their deposits.

2.2 Corporate sector

2.2.1 Consumption good firms

Quantity choice C-firms produce a homogeneous consumption good using labor and heterogeneous capital goods. Being unable to observe actual demand, the desired output, $\tilde{Y}_{it}$, is set on the basis of expected sales, S^e_{it}, as computed by means of a simple adaptive rule depending on past forecasting errors, according to equation (2.2). Additionally, in defining the planned production, firms take into account: (i) the desired inventory level, given by a fraction κ of expected sales, in order to hedge against short-term demand swings (Caiani et al., 2018), (ii) the involuntary inventories of unsold goods, inv_{it-1}, inherited from the past period, which depreciate at a rate δ^{inv}. Hence, the desired output is defined as

$$\tilde{Y}_{it} = S^e_{it}(1+\kappa) - inv_{it-1}, \tag{2.1}$$

$$S^e_{it} = S^e_{it-1} + \rho(S_{it-1} - S^e_{it-1}). \tag{2.2}$$

Because frictions in the labor or credit markets may possibly constrain firms' factor demands, the actual scale of economic activity is computed as the minimum between desired and potential output. To produce the consumption good, firms combine labor and heterogeneous capital in fixed proportions, according to a Leontief technology. Assuming labor is the abundant factor, the production function reads

$$Y_{it} = \sum_{v \in V_{it}} \omega^v_{it} k^v_{it} \bar{A}^v_{it}, \tag{2.3}$$

where V_{it} is the set of capital goods owned by firm i at time t, ω^v_{it} is the utilization rate relative to each capital vintage v, k^v_{it} and $\bar{A}^v_{it}$ are the amount of capital units of type v and its related effective productivity, respectively. As shown in equation (2.12) below, the latter depends on the ability of firm i to exploit the built-in technology of the capital vintage v.

C-firms respond to short run fluctuations in expected sales by adjusting the rate of capacity utilization as well as the required workforce, whereas the capital stock is modified according to long-run production requirements, in tune with Assenza et al. (2015).

Determination of utilization capacity Having defined the desired level of production, the required utilization rate by capital vintage, ω^v_{it}, and labor demand, N_{it}, are derived from equation (2.3). Following Caiani et al. (2018), in each period C-firms rank the available machine tools based on their built-in productivity – $v = 1, 2, 3, ...$ with the first being the most productive – and employ them in the production process starting from those with the highest quality. The desired utilization rate of capital vintage v by firm i is determined according to the following algorithm:

$$\tilde{\omega}^v_{it} = \begin{cases} 1 & \text{if} \quad \sum_{s=1}^{v-1} \tilde{\omega}^s_{it} k^s_{it} \bar{A}^s_i + k^v_{it}\bar{A}^v_i \leq \tilde{Y}_{it} \\ \frac{\tilde{Y}_{it} - \sum_{s=1}^{v-1} \tilde{\omega}^s_{it} k^s_{it} \bar{A}^s_i}{k^v_{it}\bar{A}^v_i} & \text{if} \quad \sum_{s=1}^{v-1} \tilde{\omega}^s_{it} k^s_{it} \bar{A}^s_i \leq \tilde{Y}_{it} \text{ and } \sum_{s=1}^{v-1} \tilde{\omega}^s_{it} k^s_{it} \bar{A}^s_i + k^v_{it}\bar{A}^v_i > \tilde{Y}_{it} \\ 0 & \text{if} \quad \sum_{s=1}^{v-1} \tilde{\omega}^s_{it} k^s_{it} \bar{A}^s_i \geq \tilde{Y}_{it}. \end{cases}$$

Labor demand C-firms need workers to carry out both production and R&D activities. To preserve the stock-flow consistency of the model, in fact, the research budget is used to hire workers who perform R&D activity during the current period. Hence, researchers can be thought of as external consultants employed by the innovative firm to perform temporary research projects.

Given the desired capacity utilization, $\tilde{\omega}$, and the constant capital-labor ratio, $\bar{l}_k$, labor demand for production is given by

$$\tilde{N}_{it} = \sum_{v \in V_{it}} \tilde{\omega}^v_{it} \frac{k^v_{it}}{\bar{l}_k}. \tag{2.4}$$

If labor demand $\tilde{N}_{it}$ is greater than the current workforce N_{it-1}, or if R&D investment is positive, firms post vacancies on the job market[3], hence defined as

$$J_{it} = \begin{cases} \max(\tilde{N}_{it} - N_{it-1}, 0) + \max(\frac{RD_{it}}{w_t}, 1) & \text{if } RD_{it} > 0, \\ \max(\tilde{N}_{it} - N_{it-1}, 0) & \text{otherwise,} \end{cases} \tag{2.5}$$

where w_t is the market wage uniform across firms.

The job market unfolds according to the search and matching process (cfr. Assenza et al., 2015): unemployed workers visit Z_e randomly sampled firms and get hired at the prevailing wage as they encounter one firm with available job vacancies. This means that firms can fill their open positions only if they are visited by a sufficient number of unemployed workers. It follows that, despite the absence of transaction costs on the labor market, i.e., firms can hire or fire employees at no cost, the presence of firms with job vacancies can coexist with unemployed workers looking for a job. In case the current number of employees exceeds labor requirements, i.e., $\tilde{N}_{it} < N_{it-1}$, workers in excess are randomly selected from the firm's workforce and then fired.

R&D and technological knowledge The R&D budget is determined as a constant fraction of past net profits, i.e., $RD_{it} = \sigma^c \pi^{net}_{it-1}$. The purpose of research activity carried out by C-firms is to accumulate a stock of technological knowledge, which, in turn, improves their ability to identify and employ the best machines produced by K-firms. The idea is that technological knowledge is not entirely a public good, but costly to acquire and process; as such, it requires prior R&D investment (Dosi and Nelson, 2010). Following the seminal work by Cohen and Levinthal (1989), R&D spending has a dual role in the process of knowledge accumulation: (i) to generate new technical knowledge; (ii) to increase the firm's 'absorptive capacity', i.e., its ability to assimilate external knowledge spillovers. Thus, the knowledge stock, z_{it}, evolves according to

$$z_{it} = (1 - \delta^z) z_{it-1} + RD_{it} + \gamma_{it}(\psi \sum_{j \neq i} RD_{jt}), \tag{2.6}$$

where

$$\gamma_{it} = 1 - e^{-\eta \overline{RD}_{it}}, \tag{2.7}$$

$$\overline{RD}_{it} = \xi \overline{RD}_{it-1} + (1 - \xi) RD_{it}. \tag{2.8}$$

According to equation (2.6), the knowledge base is generated both internally through firm's own R&D investment and externally by absorbing outside knowledge spillovers coming from other firms' R&D activity, with ψ indicating the degree of knowledge spillovers.

The absorptive capacity, $\gamma_{i,t} \in (0, 1)$, is determined endogenously based on firm's own R&D experience, where $\overline{RD}_{it}$ is the weighted average of current and past R&D spending with exponentially decaying weights. The knowledge stock depreciates at a rate δ^z, reflecting a sort of knowledge obsolescence. Note that, the fact that the absorptive capacity is firm-specific emphasizes the role of firms' heterogeneity in the acquisition process of external knowledge spillovers, regardless of ψ.

[3] If R&D investment is positive, the firm hires at least one researcher.

Choice of capital vintage The process of knowledge accumulation plays a crucial role in the investment dynamics. In fact, following Sylos Labini's (1967) intuition, heterogeneous firms do not have equal access to capital-embodied innovations, as we assume that this ultimately depends on their accumulated technological knowledge.

To capture this idea, we formalize the choice between heterogeneous vintages of capital goods through a logit model, where the probability for firm i of selecting a machine v is a function of the 'knowledge gap', i.e., the difference between the degree of capital vintage's technical advancement, A^v, and the firm's level of technological knowledge, z_i, both computed as relative position in their respective distribution normalized into the range (0,1). Therefore, we have

$$\mathbb{P}[\text{Firm } i \text{ selects vintage } v] = \frac{\exp\left[-\beta(\hat{A}_t^v - \hat{z}_{it})^2\right]}{\sum_{v=1}^{V} \exp\left[-\beta(\hat{A}_t^v - \hat{z}_{it})^2\right]}, \tag{2.9}$$

where

$$\hat{A}_t^v = \frac{A_t^v - A_t^{min}}{A_t^{max} - A_t^{min}}, \tag{2.10}$$

$$\hat{z}_{it} = \frac{z_{it} - z_t^{min}}{z_t^{max} - z_t^{min}}. \tag{2.11}$$

The parameter $\beta \in (0, \infty)$ in equation (2.9) represents the *intensity of choice*, determining how fast firms choose a vintage v coherent with their technological knowledge. In words, Equation (2.9) states that the probability for firm i of selecting a given capital vintage v is inversely proportional to the knowledge gap with respect to that particular technology. For instance, let us consider the case of the machine tool at the technological frontier, i.e., $\hat{A}^v = 1$. In this case, the higher the firm's technological knowledge, z_{it}, the lower the knowledge gap with respect to the best technology $(\hat{A}_t^v - \hat{z}_{it})$, the higher the probability for firm i of choosing it.

The underlying motivation is that to access and master the most efficient machines produced by innovators C-firms require to build up an in-house technical capacity. In this sense, the technological knowledge shall be considered as the firm's know-how, that is the set of skills and abilities accumulated over time by means of R&D. As such, it constitutes a form of technological barrier to entry, or rather to *use* (Dosi and Nelson, 2010), which, by influencing firms' access to technological innovations, is the ultimate driver of firms' heterogeneity and productivity differentials.

Because the choice of the capital good is stochastic, a firm may happen to buy a machine with a degree of technical advancement relatively greater than her accumulated knowledge, that is $\hat{A}^v > \hat{z}_{it}$. In this case, the knowledge gap acts as a constraint on the effective usage of vintage technology, $\bar{A}_{it}^v$. Thus, the effective productivity associated with a capital vintage v owned by firm i is defined as

$$\bar{A}_{it}^v = \begin{cases} A_t^v & \text{if } \hat{A}_t^v \leq \hat{z}_{it}, \\ \frac{2A_t^v}{1+e^{a_1(\hat{A}_t^v - \hat{z}_{it})^{a_2}}} & \text{otherwise,} \end{cases} \tag{2.12}$$

with $a_1, a_2 > 1$. The function of the effective capital productivity is displayed in figure 2.1. Here we can observe that firm i can fully exploit the productivity of vintage v as long as her degree of technological knowledge is higher than or equal to the capital's technical advancement. Otherwise, the knowledge constraints become tighter the higher the size of the knowledge gap.

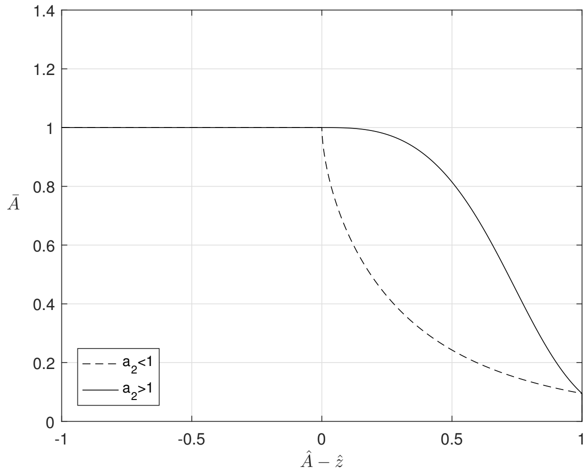


Figure 2.1: Effective productivity of capital vintage, $\bar{A}^v_{it}$, as a function of the knowledge gap, $\hat{A}^v_{it} - \hat{z}_{it}$. The slope of the function represents the intensity of the knowledge constraints.

Investment demand Following Assenza et al. (2015), we assume that capital is fixed in the short run: the investment goods acquired in t can be employed in the production process starting from $t+1$. That being the case, the demand for capital by C-firms aims to meet long-run production needs, rather than the short-run market fluctuations.

To determine the investment demand, in particular, C-firms compare the long-run desired output with the current potential output, given the effective productivity of the selected vintage. The demand for capital is thus formalized as

$$I_{it} = \Big(\frac{\bar{Y}_{it-1}}{\bar{\omega}} - \hat{Y}_{it}\Big)\frac{1}{\bar{A}^v_{it}}, \tag{2.13}$$

where

$$\bar{Y}_{it-1} = v\bar{Y}_{it-2} + (1-v)\tilde{Y}_{it-1} \tag{2.14}$$

$$\hat{Y}_{it} = \sum_{v \in V_{it}} (1-\delta)k^v_{it}\bar{A}^v_{it}. \tag{2.15}$$

The long-run desired production is computed after discounting the weighted-average planned output in equation (2.1) for the target utilization rate, $\bar{\omega}$. Potential output in equation (2.15) corresponds to the maximum level of production a firm can achieve by fully employing the entire capital stock inherited from the last period, depreciated at a rate δ, similar to Dawid et al. (2019). In other words, equation (2.13) states that in case firms are not able to produce as much as they desire with the existing capacity, they will buy additional capital units from the previously selected supplier.

The law of motion for capital at the firm level, once taking into account the batch of heterogeneous machines, is given by

$$K_{it+1} = \sum_{v=1}^{V_{it}} (1-\delta)k^v_{it} + I_{it}. \tag{2.16}$$

Price setting Similarly to Dosi et al. (2010), C-firms set the price by charging a mark-up μ_{it} on the unitary labor cost, i.e.

$$p_{it} = (1 + \mu_{it})c_{it}. \tag{2.17}$$

with $c_{it} = \frac{w_t N_{it}}{Y_{it}}$. In line with Kalecki (1942), the mark-up is determined endogenously and updated every period depending on the firm's degree of market power, as manifested in its individual market share. In particular, the mark-up rule is updated every period according to the rule

$$\mu_{it} = \begin{cases} \mu_{it-1}(1 + \mu_t^r) & \text{if} \quad f_{it} > \bar{f}_t \ \ \& \ \ \Delta f_{it} > 0 \\ \mu_{it-1}(1 - \mu_t^r) & \text{if} \quad f_{it} < \bar{f}_t \ \text{ or } \ \Delta f_{it} < 0 \\ \mu_{it-1} & \qquad \text{otherwise.} \end{cases} \tag{2.18}$$

Equation (2.18) states that if the firm's market share, f_{it}, is above (below) the average share, $\bar{f}_t$, *and* increasing (*or* decreasing) with respect to the previous period, the mark-up will be adjusted by a positive (negative) number randomly drawn from a Folded Normal distribution with parameters $(\mu_{FN_3}, \sigma^2_{FN_3})$. Note that, as documented by Alvarez et al. (2006), mark-ups adjust faster downward than upward. The underlying assumption is that firms are reluctant to raise the price too quickly for fear of loosing their market shares, while they are more prone to reducing it in order to re-gain competitiveness.

Profits, dividends and net worth When the consumption good market closes, C-firms compute profits as the sum of sales and nominal variation of inventories minus wage bill, capital depreciation, interest payments on loans, R&D expenditure and inventories depreciation.[4] If positive, the firm distributes a fraction *div* of surplus to the owner in the form of dividend, net of taxes. The gross and net profits equations thus read

$$\pi_{it} = p_{it}Q_{it} + (inv_{it}p_{it} - inv_{it-1}p_{it-1}) - w_t N_{it} + \tag{2.19}$$

$$- \sum_{v \in K_{it}} \delta \omega_{it}^v k_{it}^v - \hat{r}_{it} L_{it} - RD_{it} - \delta^{inv} inv_{t-1} p_{it-1}, \tag{2.20}$$

$$\pi_{it}^{net} = \max((1 - div)\pi_{it}, 0).$$

Net profits (or losses) pile up to equity, which evolves as

$$E_{it+1} = E_{it} + \pi_{it}^{net}. \tag{2.21}$$

In order to check for the stock-flow consistency of the model, we compare firms' net worth as computed in equation 2.21 with the net worth measured as assets minus liabilities. Firms' assets are given by the sum of capital value and liquidity, while liabilities consist of corporate debt. Liquidity is updated by taking into account all cash inflows and outflows, including debt installments, as shown in the Appendix.

Whenever net worth turns negative or liquidity falls short of financial obligations, i.e., interests and debt installment, the firm goes bankrupt and exits the market. Given that, for simplicity, the number of firms is assumed to be constant over time, each bankrupted firm is substituted by a new entrant, recapitalized by means of the owner's wealth, while the cost of bad debt is born by bank's equity which is reduced accordingly.

[4]With regards to the interest payments, the rate on loans set by the bank for a specific firm can vary over time, therefore $\hat{r}$ is the weighted average of past interest rates with time-varying weights. The reader is addressed to Assenza et al. (2015) for a detailed explanation.

2.2.2 Capital good firms

Innovation and imitation K-firms produce heterogeneous machine tools using only labor according to a Make-to-Order plan, meaning that the production orders are based on C-firms' investment demand, with no inventory accumulation. Following Dosi et al. (2010), each K-firm is characterized by a technology (A^v_{jt+1}, B^k_{jt+1}), where the former represents the productivity associated with the machine tool produced by firm j, while the latter indicates the labor productivity of firm j itself. Innovators strive to improve the 'quality' of their technologies and reduce the production costs. To do that, they invest a constant fraction, σ^k, of net profits in R&D to perform innovation and imitation activities, depending on parameter $\chi \in (0, 1)$, i.e.

$$RD_{jt} = \sigma^k \pi^{net}_{jt-1}, \tag{2.22}$$

$$IN_{jt} = (1 - \chi) RD_{jt}, \tag{2.23}$$

$$IM_{jt} = \chi RD_{jt}. \tag{2.24}$$

In line with the evolutionary tradition of technical change (Nelson and Winter, 1982; Dosi et al., 2010; Caiani et al., 2018), innovation and imitation activities follow a two-step stochastic process.

The first step determines whether or not the firm has the opportunity to innovate and imitate, defined as a random drawn from a Bernoulli distribution, with parameters Pr^{inn}_{jt} and Pr^{imi}_{jt}, i.e.

$$Pr^{inn}_{jt} = 1 - e^{-\varsigma IN_{jt}}, \tag{2.25}$$

$$Pr^{imi}_{jt} = 1 - e^{-\varsigma IM_{jt}}, \tag{2.26}$$

with $\varsigma > 0$. Hence, the probability to innovate and imitate is positively influenced by the scale of R&D investment.

In the second step, firms having the opportunity to innovate draw from a Folded Normal distribution a pair of technological innovations (Δ_A, Δ_B), defined as productivity gains of the respective production techniques, according to

$$A^v_{jt+1} = A^v_{jt}(1 + \Delta_A), \text{ where} \Delta_A \sim FN(\mu_{FN_1}, \sigma^2_{FN_1}), \tag{2.27}$$

$$B^k_{jt+1} = B^k_{jt}(1 + \Delta_B), \text{ where } \Delta_B \sim FN_2(\mu_{FN_2}, \sigma^2_{FN_2}). \tag{2.28}$$

When a K-firm draws the opportunity to imitate, it will search among the Z_{imi} more technically advanced firms and randomly pick one of their technologies.

Finally, firms compare the technological opportunities arising from innovation and imitation process and choose to produce the techniques with the highest built-in productivity.

Labor demand As labor is the only input of production, K-firms employ R&D expenditures to hire workers at the prevailing market wage w_t. If labor demand is greater than current workforce, K-firms will resort to the labor market to cover the gap, randomly choosing the required workers from the pool of the unemployed. Otherwise, if there is a surplus of workers, K-firms can get rid of them at zero costs.

Price setting Similarly to C-firms, capital good producers set the price by charging a mark-up over the unit cost of production c_{jt}, being the latter defined as market wage over labor productivity, B^k_j. However, differently from C-firms, the mark-up of K-firms is assumed to be fixed, as in Dosi et al. (2010). Hence, the capital good price is given by

$$p^v_{jt} = (1 + \bar{\mu}^k) c_{jt}, \tag{2.29}$$

where $\bar{\mu}^k$ is the mark-up, constant and uniform across firms, while $c_{jt} = \frac{w_t}{B_j^k}$ is the firm's unit labor cost.

Profits, dividends and net worth Profits (or losses) are computed as the difference between sales and variable costs plus R&D spending. If positive, K-firms distribute fraction div of surplus to the owner in the form of dividend, net of taxes. The gross and net profit equations and the law of motion of equity for K-firms thus read

$$\pi_{jt} = p_{jt}Q_{jt} - c_{jt}Q_{jt} - RD_{jt}, \tag{2.30}$$

$$\pi_{jt}^{net} = \max((1 - div)\pi_{jt}, 0) \tag{2.31}$$

$$E_{jt+1} = E_{jt} + \pi_{jt}^{net}. \tag{2.32}$$

2.3 Household sector

The households sectors is composed by W workers and K capitalists. The capitalist is the single owner of either a consumption or a capital good firm, such that $K = F + N$. Each agent receives an after tax income, Y_{ht}, where

$$Y_{ht} = \begin{cases} (1 - \tau^w)w_t & \text{if employed worker,} \\ sw_t & \text{if unemployed worker,} \\ (1 - \tau^k)div \cdot \pi_{ft-1} & \text{if capitalist receiving dividends,} \end{cases} \tag{2.33}$$

where $h \in \{w, f\}$ indicates whether agent h is a worker or a capitalist, with $f \in \{i, j\}$ for consumption and capital good producers, τ^w and τ^k are the tax rates on, respectively, labor and capital income, while s is the unemployment subsidy rate, computed as a fraction of current wage. Workers supply one unit of labor in exchange for a wage. The latter is uniform across firms and evolves over time depending on the average productivity growth g_{A_t} according to

$$w_{t+1} = w_t(1 + \alpha g_{A_t}). \tag{2.34}$$

where α is the elasticity of nominal wage with respect to productivity.

Capital income is given by the sum of dividends that capitalists receive both from their own business and the bank, split in equal shares amongst owners.

The household's demand for consumption goods is a linear function of disposable income and financial wealth. Based on the well-known Keynesian principle according to which the saving rate is increasing along income distribution, we assume that workers and capitalists have different propensities to consume out of income, namely c_w and c_k, respectively, with $0 < c_k < c_w < 1$. The resulting savings pile up to financial wealth, held in the form of bank deposits D_{ht-1}. The consumption budget can be specified as

$$C_{ht} = c_h(1 - \tau)Y_{ht} + c_f D_{ht-1}. \tag{2.35}$$

where $0 < c_f < 1$ is the uniform propensity to consume out of wealth.

Having defined the consumption budget, the choice of the goods to buy is determined through the search-and-matching mechanism. Differently from the labor market, the partner's selection is not purely random, but is governed by a preferential attachment scheme, according to which consumers tend to be loyal to their previous seller. In particular, when the goods market opens, each household compares the price of the C-firm where she shopped in the previous period with the best price from $Z_c - 1$ randomly visited firms. If the new price is lower than the old one, the consumer will switch to the new supplier with a certain probability, Pr_s, which is increasing (in a non-linear way) with the price gap: the higher the percentage difference between p_{old} and p_{new}, the higher the probability of switching to the new partner, as in Delli Gatti et al. (2010). In symbols: $Pr_s = 1 - e^{-\lambda(p_{new}-p_{old})/p_{new}}$. The shape of the probability function is determined by λ, which represents the *intensity of choice*, i.e., how fast consumers switch to the most convenient supplier. It might happen that the amount of output supplied by the selected partner is lower than the household's demand for consumption goods. In this case, the consumer will resort to the other firms in the list, sorted in ascending order based on price.

2.4 Banking sector

The bank collects deposits from households at zero interest rate and provides loans to C-firms to cover the financing gap. The credit market largely borrows from our parental model (Assenza et al., 2015), to which the reader is addressed for a detailed illustration. Here we limit ourselves to provide a summary overview of its essential features.

After receiving credit demands from borrowing firms, the Bank determines both price and quantity of the loan for each borrower depending on her financial situation. The firm-specific interest rate is formulated as an exogenous risk free rate r charged with a mark-up increasing with the borrower's financial fragility. The latter is measured by the time-to-default, TT, which is inversely related to the firm's leverage l_{it}, i.e., the lower the leverage, the higher the time to default, the lower the interest rate, or

$$r_{it} = g(r, TT(l_{it})), \tag{2.36}$$

$$l_{it} = \frac{D_{i,t}}{E_{it} + D_{it}}. \tag{2.37}$$

Furthermore, the Bank sets a maximum amount of loans to be extended to each borrower on the basis of a tolerance level for the potential loss on credit, determined as a fraction on its own net worth. It follows that the bank may not be able to satisfy entirely firms' demand for loans, in which case, C-firms will be forced to re-scale the level of activity due to lack of funds.

2.5 Public sector

The public sector is modelled based on Assenza et al. (2015), where the Government levies a constant tax rate on labor and capital income and pays out unemployment benefits to non-working individuals. The unemployment subsidy is computed as a fraction, s, of the market wage. Whenever public expenditure exceeds tax revenues, the Government finances the resulting deficit by issuing Treasury bonds, bought by the Bank, at a fixed risk-free interest rate.

3 Simulation results

3.1 Calibration and initialization

To empirically validate the model, we follow a consolidated procedure in the macro ABM literature, also known as "output validation" (Delli Gatti et al., 2018). In the first place, the goal is to establish a baseline scenario, against which we will evaluate the effects of alternative policies and institutional frameworks. To carry out this task, we calibrate the model such that it is able to replicate a wide ensemble of empirical regularities at different levels of aggregation. The parameters' values employed in the model's equations are summarized in Table B.1 (in Appendix). Furthermore, another challenging task before resorting to computer simulations concerns the initialization of the model's variables. To comply with the stock-flow consistency principle, we require that the initial interrelated matrix of balance sheets among agents respects the double-entry bookkeeping system, according to which one agent's asset corresponds to someone else's liability. The initialization procedure involves the following steps:

- C-firms are endowed with an initial amount of capital goods such that aggregate output is associated with a desired rate of unemployment, i.e. 5%, given the initial value of labor productivity, A_0, and the constant capital-labor ratio $\bar{l}$.

- The value of C-firms' liquidity, held in the form of bank deposits, is set equal to the value of capital stock. Since we assume there is no private debt at $t = 1$, C-firms' net worth is given by the sum of capital value and liquid assets.

- Because K-firms use only labor, their net worth is simply equal to the value of liquidity, which is a fraction of C-firms' deposits.

- The financial wealth of households is held in the form of bank account and corresponds to 50 monthly wages, with $w_1 = 1$, in order to guarantee a sufficient saving buffer.

- Given that there are no initial corporate loans, the bank's balance sheet consists of Government bonds on the asset side and the sum of firms and households' deposits on the liabilities side. The initial stock of public bonds is a multiple of total deposits to make sure that the bank's equity is positive.

3.2 Empirical validation

Based on the parameter values and the initialization procedure described above, the empirical validation is performed by running a set of 25 Monte Carlo simulations with different random seeds for 1000 time periods. The artificial time series are constructed by taking averages across simulation runs and then compared with real data. Both simulated and real data are treated with the Hodrick-Prescott (HP) filter in order to isolate the cyclical component from the trend. The observed time series were downloaded from the FRED database and accounts for quarterly data ranging between 1955-2013 for unemployment, and from 1947 to 2013 for GDP, consumption and investment.

Figure 3.1 displays the last 100 periods for a selection of simulated time series. It can be seen that the model generates a regular self-sustained growth pattern, with ever-increasing trends in

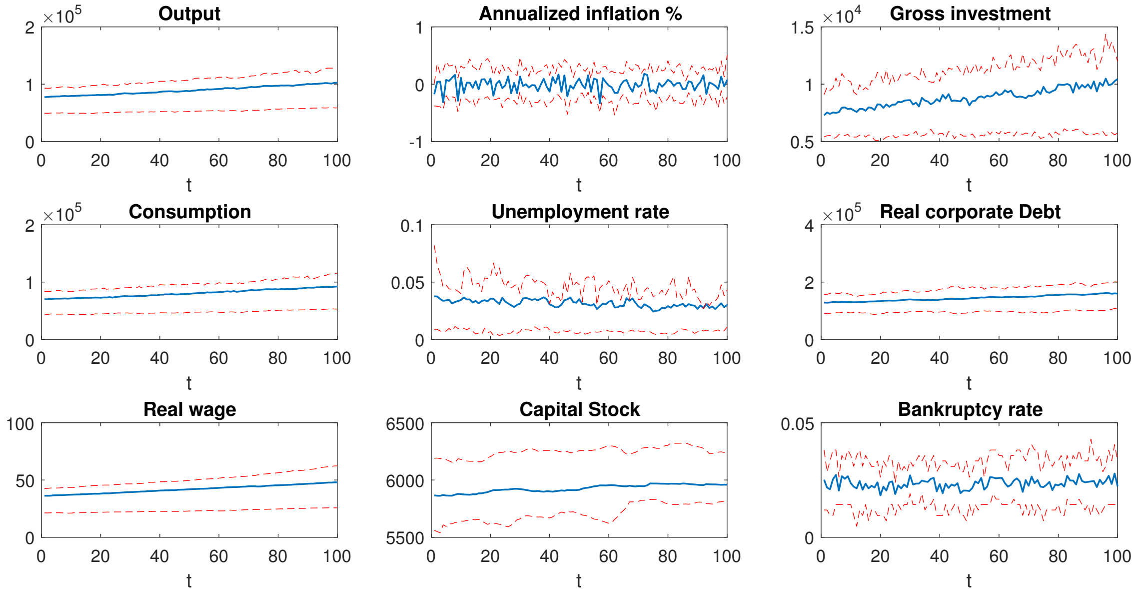


Figure 3.1: Time series of cross-MC means of selected macroeconomic variables. Last 100 periods are reported.

both real and financial variables characterized by persistent short-term fluctuations and recurrent bankruptcies. This is the result of the interplay of the Schumpeterian innovation-fuelled growth process and Minskyian instability-enhancing financial accelerator.

To better appraise this figure, it is worth looking at the time series of trend and cyclical components separately, obtained after applying the HP filter to a set of macroeconomic variables, as shown in figure 3.2. The plot illustrates that, in line with the empirical evidence on business cycle (Stock and Watson, 1999), investment is systematically more volatile than GDP and consumption, with all of them growing at positive steady rates.

Following Assenza et al. (2015), figure 3.3 compares the autocorrelation and cross-correlation of GDP, consumption, investment and unemployment obtained from simulated data with their empirical counterparts. The autocorrelation structure of the two series look remarkably similar. The cross-correlation plots show that consumption and gross investment are pro-cyclical with respect to GDP, while unemployment rate is anti-cyclical, as evidenced in observed data. From this validation exercise, we can safely say that the model does a fairly good job at reproducing the selected empirical regularities for the U.S. economy.

3.3 Economic analysis

Given the complex structure of interaction amongst heterogeneous agents and the multiple non-linear dynamic equations, the model does not lead to a closed-form analytical solution. Hence, to address our research question, we resort to the tool of computer simulations. The main goal of this paper is to analyse the underlying causes of the endogenous formation of market concentration and its macroeconomic consequences, both in the short and long run. Therefore, first we are going to inspect the emergent dynamics of the model in the first 250 periods from

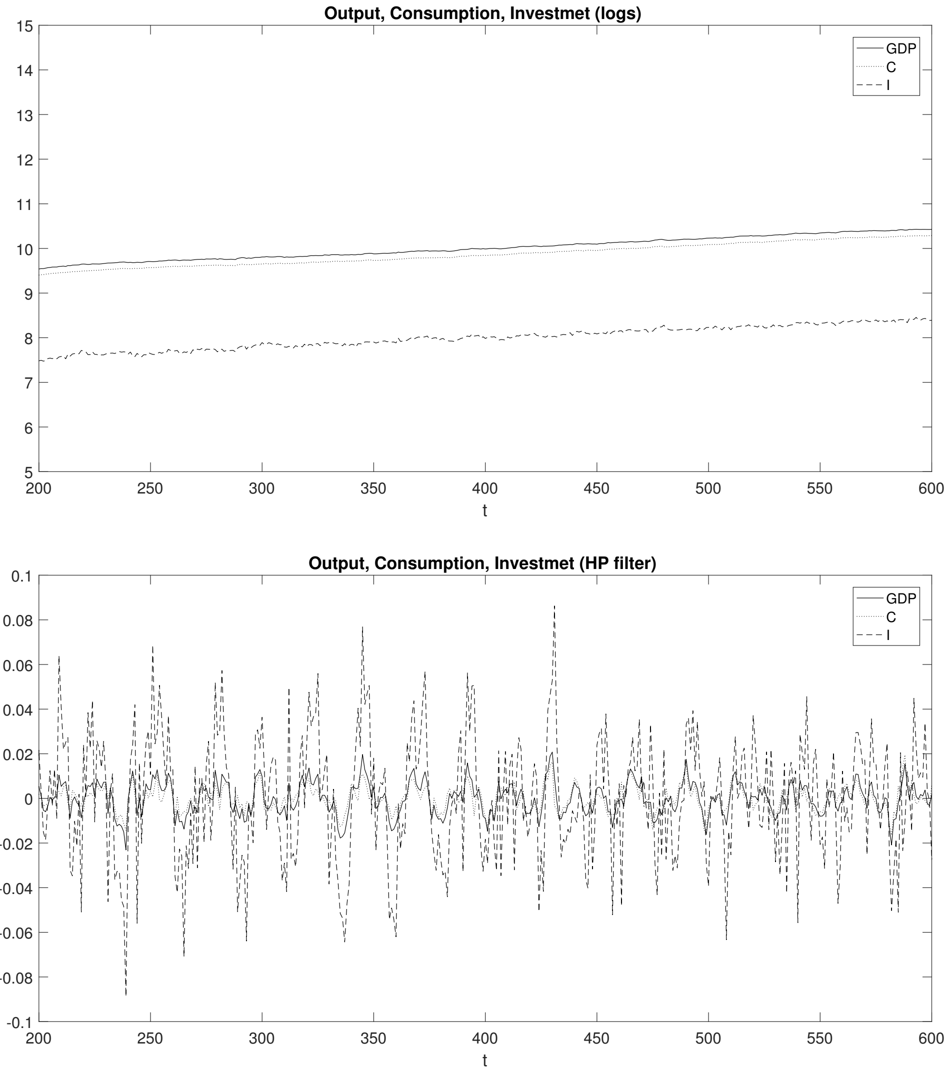


Figure 3.2: Cross-MC average of real GDP, consumption and investment. Trend and cyclical components are obtained by applying the HP filter.

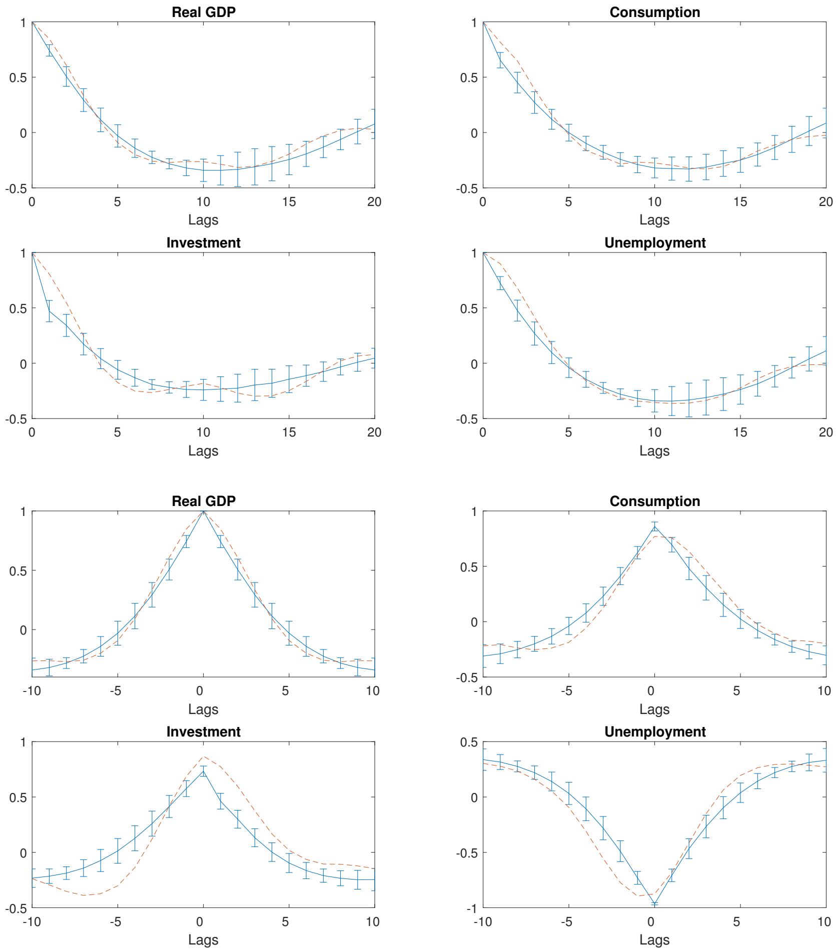


Figure 3.3: Autocorrelation (top) and cross-correlation (bottom) of GDP, consumption, investment and unemployment for simulated (solid blue) and empirical (dashed red) data. All variables are treated with the HP filter to isolate the cyclical component.

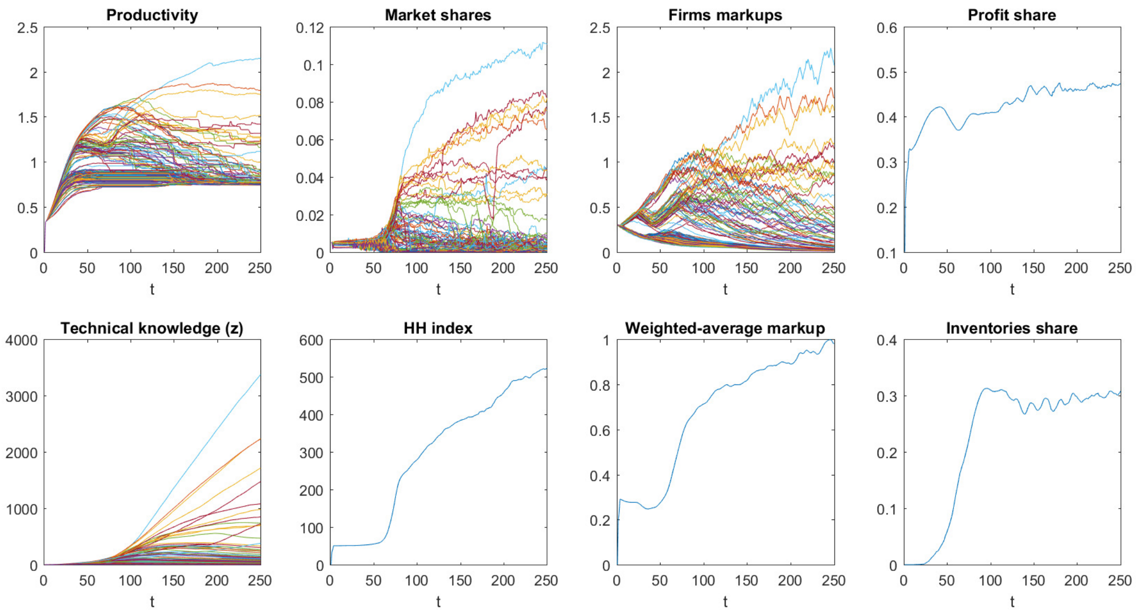


Figure 3.4: Dynamics of selected aggregate and firm-level variables; first 250 periods from one representative simulation.

one representative simulation. Afterwards, we perform Monte Carlo simulations to examine the long-term macroeconomic dynamics and following policy implications.

3.3.1 The story of concentration: a short run focus

Figure 3.4 collects a set of plots displaying the time series of both aggregate and firm-level variables in the first 250 periods from one representative simulation of the model. This allows us to dig into the microeconomic mechanisms underlying the macroeconomic dynamics.

In every simulation run, after a short period of transition, the model endogenously generates a wave of market concentration, that is a situation in which a relatively small number of firms ends up holding a vast share of the market, causing a sharp increase in the Herfindahl-Hirschman index. From the left-hand panels, we notice that the leading firms are those that are able to develop a better production capacity, using their accumulated technical knowledge to invest in more efficient capital-embodied technologies and thus gaining a competitive advantage. This outcome is reminiscent of Autor et al.'s (2020) notion of "superstar" firms. Yet, contrary to their HANK model wherein firms are initially endowed with different productivity levels, in our agent-based model superstar firms endogenously emerge out of the normal operation of the economy, without resorting to different initial conditions. In the jargon of complexity theory, this is an *emergent property* of the system. Remind that, on the capital goods market, the firms' choice between heterogeneous vintages of machine tools is a function of the "knowledge gap": throughout the process of capital accumulation, firms with greater technological knowledge are more likely to adopt the more efficient machines, thereby achieving faster production gains and and larger market shares. The process of rising concentration, thus, spontaneously emerges as a by-product of technical progress that engenders technological discontinuities, as reflected in the

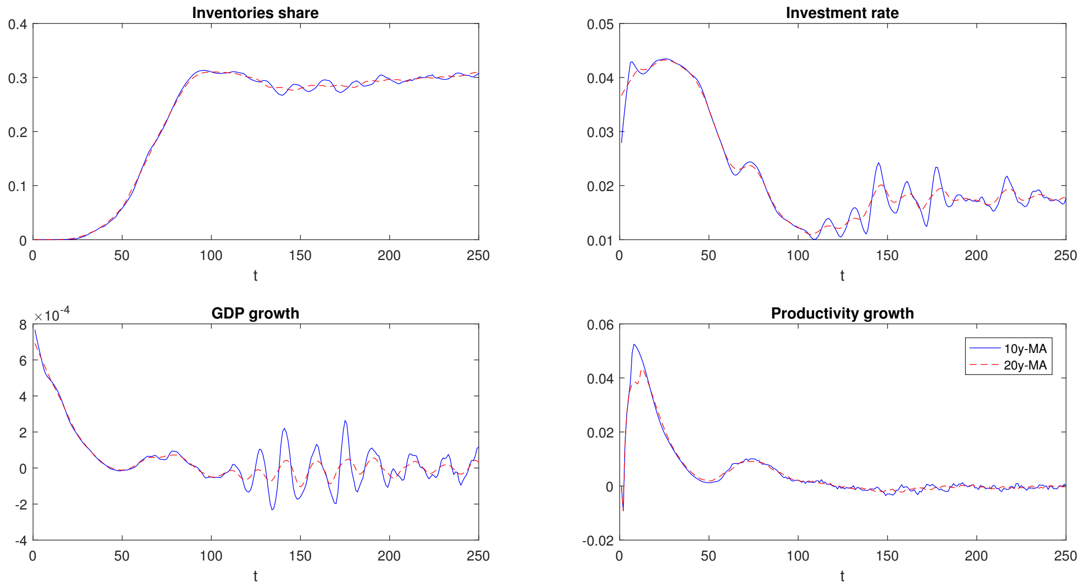


Figure 3.5: Inventories and investment share (5- and 20-years moving average); GDP and productivity growth rate (30- and 50-years moving average).

systematic productivity differential across C-firms.

Furthermore, it is important to stress that the relationship between technological knowledge, productivity and market share is reinforced over time due to a positive feedback within the model dynamics: as the extra profits stemming from larger market shares are partially reinvested in R&D, *in the absence of* consistent knowledge spillovers and *given* the heterogeneity among capital goods, the knowledge distribution becomes more and more polarized between leaders and followers, making it difficult for the latter to buy better machines and thus to catch up with the former. Dosi and Nelson (2010) refer to this peculiar feature of technical change as the "cumulativeness of innovative success", whereby innovative advances are based on past realizations of the stochastic process. Moreover, our findings corroborate the authors' presumptions that such a 'success breeds success' kind of dynamics is particularly relevant in a world of "knowledge-based dynamic increasing returns". Since the process of knowledge accumulation is history- and path-dependent, the lack of investment in R&D may foreclose the future development of technological structure, determining persistent productivity and market shares differentials. Note that, as will become clearer in the following discussion, the two underlying assumptions about knowledge spillovers and capital heterogeneity are paramount in order for market concentration to be high and persistent over time.

So far, we have dealt with the underlying causes of rising concentration; now let us shift the focus on the second half of the story, that is the macroeconomic consequences.

From the right-hand panels in figure 3.4, it can be seen that firms with larger market shares are able to increase their profit margins. Remind from the pricing rule in equation (2.18) that the mark-up is set according to the firm's degree of monopoly power. In particular, one firm adaptively reviews the mark-up upwards if its market share is high and increasing over time. This is evidently the case for leading firms, which, thanks to the improved productive capacity and low unitary costs, can raise their mark-ups without incurring in a loss of market share. Moreover, as the weight of large firms grows over the economy, the increase in the weighted-average mark-up, adjusted by individual shares, leads to an increase in the profit share, which goes from 30% to 45% of total income – approximately the magnitude of the change in income shares that western countries have witnessed in the last four decades (Autor et al., 2020). In so far as wage and profit earners have different marginal propensities to consume, a redistribution of income from the bottom to the top implies a decline in the aggregate consumption expenditure, as reflected in the rising share of unsold goods (bottom-right panel).

Consequently, C-firms interpret the higher inventories share as a symptom of a shortage in aggregate demand and review the capacity utilization rate accordingly. Indeed, from equation (2.1), an increase in the warehouse stock has a negative impact on the desired scale of production, which, in turn, affects the utilization rate of the existing plants, as defined in equation (2.4). In a context of low demand and excess capacity, C-firms do not have incentive to invest in new capital formation. As a result, the slowdown of capital accumulation gives rise to a tendency to stagnation, as manifested in the falling growth rates of output and productivity in figure 3.5.[5] Following the lessons from Sylos Labini (1967) and Steindl (1976), therefore, the economic system may spontaneously reach a state of stagnation as a result of changes in market structure and income distribution, triggered by technical progress and market power. As Steindl (1976) put it, "[t]he tendencies towards oligopoly discovered at the microeconomic level will cause a tendency towards stagnation at the macroeconomic level."

Let us remark that, coherent with the agent-based modelling philosophy (Dawid and Delli Gatti, 2018; Dosi and Roventini, 2019), all the outcomes we have just described are *emergent dynamics* of the model, i.e., regular patterns the system is able to reproduce through the adaptive behaviour of heterogeneous agents interacting in decentralized markets, given the behavioural rules and market protocols discussed in the previous section. In the rest of the paper, instead, we are going to explore the model dynamics under different scenarios by switching the values of key parameters, in order to capture the role of different regulatory or institutional frameworks on the agents behaviour and macroeconomic outcomes.

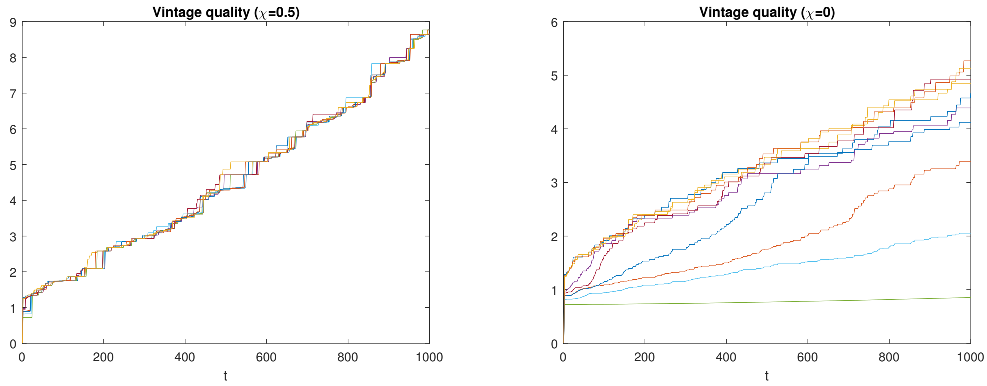
3.3.2 Long-term consequences: the role of legal entry barriers

It has been shown that, in the early stage of a representative simulation, the model endogenously generates a wave of market concentration, driven by technical change, which impacts on income distribution and economic dynamics. A natural question is: what happens next?

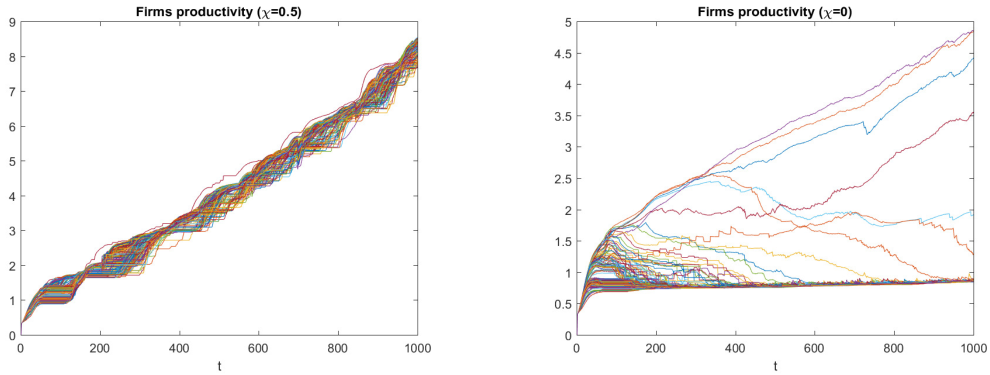
To explore the model properties in the long run, we confront the benchmark case with an alternative scenario in which K-firms are not allowed to imitate. More specifically, the parameter χ in equation (2.24) is set equal to 0, from 0.5 in the baseline setting, so that the entire R&D budget is spent on innovation. We can think of the alternative scenario as a situation in which a strict innovation patent system is in place, whereby legal entry barriers prevent K-firms from imitating their competitors' technologies. This simulation experiment allows us to fully appraise the role of both knowledge gap and technological discontinuities on the process of market concentration and its long-term effects on the economic performance.

Before looking at the model dynamics at the aggregate level, it is worth dwelling on the dynamics of K-goods' technology and C-firms' productivity from one representative simulation. Figure 3.6 shows that the imitation activity carried out by K-firms brings about a convergence in the capital goods' productivity (a-left), causing a significant reduction in the technological discontinuities among C-firms (b-left). On the other hand, in the no-imitation scenario, such a

[5] This analysis of investment allows to combine Keynes's theory of effective demand and business cycle with Schumpeter's theory of innovation and economic development, as previously proposed by Dosi et al. (2010).



(a) Vintage quality of K-firms



(b) Labor productivity of C-firms

Figure 3.6: Imitation (left) vs no-imitation (right) scenarios

convergence does not occur and, consequently, the productivity differences across C-firms increase over time (b-right).

Interestingly, it emerges that a strict correlation exists between the technological evolution in the capital good sector and changes in market forms in the consumption good sector: in presence of relatively homogeneous capital goods due to the imitation activity by K-firms, large firms in the C-sector are not able to exploit their "knowledge advantage" to buy relatively more efficient techniques than their competitors, allowing the laggards to catch up. Conversely, a persistent heterogeneity among capital goods makes the "knowledge gap" mechanism more effective, leading to growing differences in productivity and technological structure across C-firms.

Therefore, we find that in order for technological discontinuities to be high and persistent over time it is necessary that capital goods remain considerably different from each other, that is to say, the imitation activity by capital good producers is limited.

These differences in the technological structure across C-firms in the two scenarios are reflected in the evolution of unit costs, mark-ups and prices displayed in figure 3.7. For the sake of clarity, we split the population of firms in two groups with respect to size, i.e., large and small firms, depending on whether their level of sales is above or below the median. In both scenarios, the rise in technological discontinuities that occurs during the initial wave of concentration generates a discrepancy in costs and mark-ups among groups of firms. Then, whereas such differences

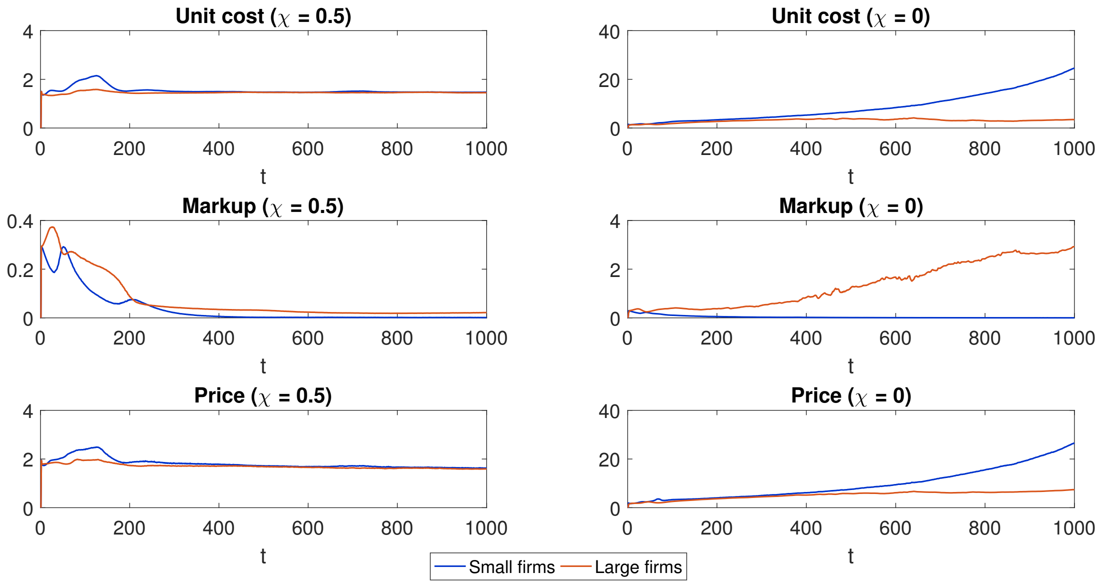


Figure 3.7: Evolution of unit costs, mark-ups and price of large (orange) and small (blue) firms in the imitation (left-hand) and no-imitation (right-hand) scenario. Mean values across 25 Monte Carlo simulations.

are soon re-absorbed when imitation is allowed (left-hand panels), in the no-imitation scenario (right-hand panels) large and small firms experience two diverging trends shaped by the increasing differences in the technological structure. On the one hand, nominal wages growth and weak technical advancements determines rising unit costs for small firms. On the other hand, large productive firms can set higher mark-ups without this translating into a loss of market shares. In fact, the laggards fail to recover competitiveness despite low mark-ups as they are forced to increment prices to cover the rising costs.

The same pattern emerges by looking at the evolution of market structure over time, as illustrated in figure 3.8. Here we show the distribution of firm size measured in terms of output and number of employees in different time periods of the simulation, i.e., $t = 100, 800$. Firm size distribution is averaged over all Monte Carlo runs: at the selected time, for each rank the mean value of the considered variables across the runs is depicted on a log-log scale. We observe that, after 100 periods (top panels), in the midst of the first concentration wave, the two scenarios look quite similar where the distribution for both variables exhibits fat tails and substantial heterogeneity. As time passes, however, in line with previous findings, the imitation scenario is characterized by relatively more homogeneous firms, while the size distribution becomes even more skewed in the alternative scenario. In other words, there are fewer firms producing increasingly larger output levels, indicating a higher degree of concentration.

It will soon become clear that such differences in the technological patterns and market forms across firms and sectors entail important macroeconomic consequences in terms of income distribution and economic growth. Figure 3.9 collects a set of plots displaying aggregate time series, averaged across 25 Monte Carlo repetitions, for both imitation and no-imitation scenario. In this way, we are able to assess the role of legal entry barriers on macroeconomic dynamics in the longer run.

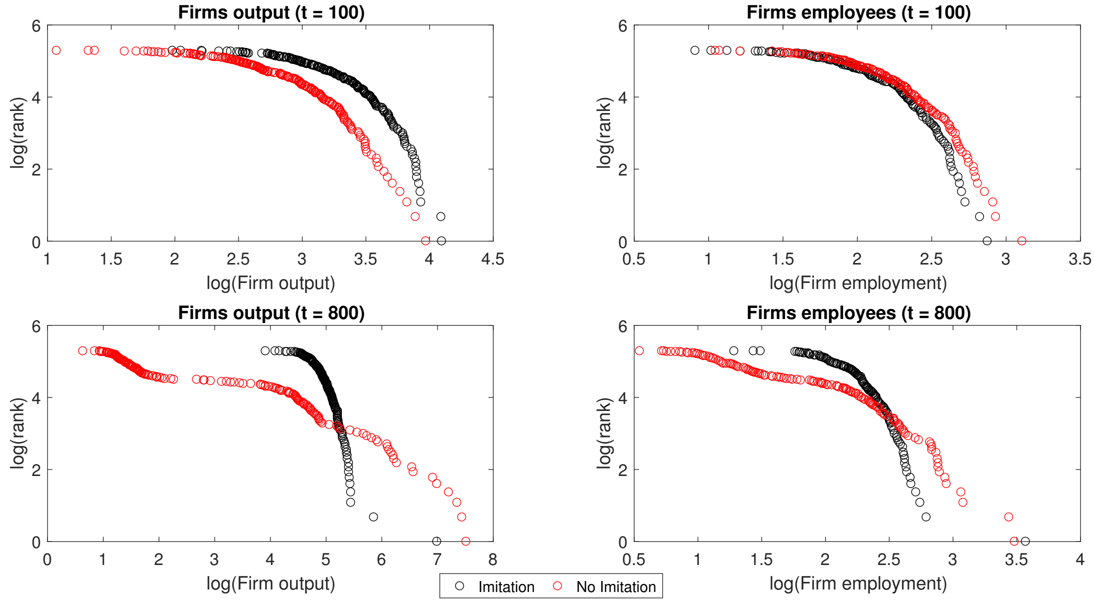


Figure 3.8: Distribution of firms size in terms of output and number of employees at t=100 (top half) and t=800 (bottom half) in the imitation (black) and no-imitation (red) scenario. Mean values across 25 Monte Carlo simulations.

It can be seen that, after the initial wave of market concentration, in the imitation scenario (black curve), the economy quickly returns to a competitive stage, characterized by low HH index and mark-up, as well as high wage share and consumption. By contrast, when imitation is not allowed (red curve), the process of market concentration experiences an upward trend, driven by rising technological discontinuities[6], determining a steady increase in the mark-up, profits and inventories share, while GDP is significantly lower compared to the baseline scenario. The duration of market concentration, thus, depends on the corporate sector's ability to reproduce technological discontinuities within the system, which, in turn, is related to the process of diffusion of technological innovations amongst K-firms and C-firms' possibility of exploiting knowledge differentials.

Indeed, by reducing the knowledge gap with respect to all machine tools available on the market, the convergence between heterogeneous capital goods brought about by the imitation activity by K-firms undermines the dominant position of oligopolistic firms, which eventually loose their market power and thus their ability to extract larger profit margins. As a result, the ensuing reduction in income inequality strengthens aggregate demand and fosters a competitive and self-sustained growth process. Such a counter-tendency does not occur in the no-imitation scenario. In this case, in fact, the persistent character of technological discontinuities enables giant firms to consolidate their market position to the extent that the ever-growing concentration can unfold its negative effects on income distribution and aggregate demand also in the long run.

Table 3.1 provides a quantitative comparison of the model outcomes under different patent system regulations. It shows that, when K-firms are not allowed to imitate, the concentration index is nearly one order of magnitude higher than in the baseline scenario, which implies a

[6]We measure technological discontinuities as the standard deviation of the productivity of consumption good firms over their average productivity.

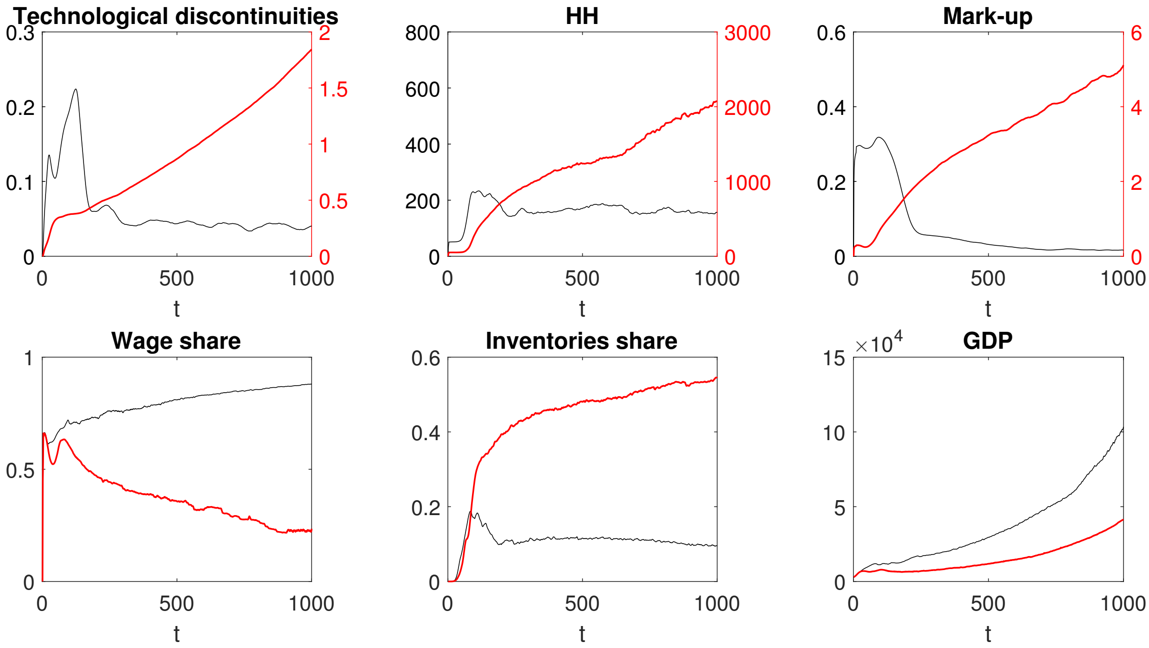


Figure 3.9: Time series of selected macro variables in the imitation (black) and no-imitation (red) scenario. Mean values across 25 simulations.

remarkable increase in the average mark-up as well as a 60% reduction in the last year GDP level. Also, under the no-imitation scenario, the chronic excess capacity due to lower demand leads to a twice higher unemployment rate and +5% in the deficit-GDP ratio, because of the grater disbursement of unemployment subsidies.[7]

In line with Sylos Labini (1967) and Steindl (1976), our findings suggest that tendency to stagnation arising from an oligopolistic market structure requires a more expansionary fiscal policy. In other words, the economic system is increasingly dependent on external stimuli to compensate for the structural deficiency in aggregate demand due to the unequal distribution of income. Albeit from a different framework, the modern theorists of the secular stagnation hypothesis reach remarkably similar policy conclusions.[8] We will further explore the role of fiscal and other policies in the next Section.

Finally, it is interesting to note that despite aggregate leverage being somewhat lower in the no-imitation scenario, the rate of bankruptcy jumps from 3% to 30%. This is due to the recurring defaults by a considerable number of small unproductive firms which fail to catch up with the leaders. Yet, because they have weak growth opportunities, their level of debt is quite small. On the other hand, large firms are able to finance investment projects by means of internal resources due to rising mark-ups and better financial conditions. As a result, the aggregate leverage in the concentrated economy is lower, even though the number of defaults is much higher.

[7]Note that, in these simulation settings, the Government is not subject to any fiscal constraints: public budget is left free to adapt to business fluctuations and the resulting public bonds are entirely purchased by the Bank. In the next Section, the effects of alternative policy regimes will be explored.

[8]See Summers (2014) and Krugman (2014) for a discussion about the 'new secular stagnation hypothesis'. For a critical review of its neoclassical theoretical underpinning, see Di Bucchianico (2020).

	Imitation	No Imitation
GDP growth rate (%)	0.2453 (0.0006)	0.2015 (0.0011)
GDP std	0.0169 (0.0020)	0.0243 (0.0114)
Unemployment rate	0.0903 (0.0118)	0.1838 (0.0770)
HH index	168.677 (0.6895)	1303.527 (6.0247)
Mark-up	0.0549 (0.0246)	3.2579 (1.7036)
Profit share	0.1915 (0.0135)	0.6507 (0.1404)
GDP last year	1	0.4008
Consumption/GDP	0.8719 (0.0074)	0.4900 (0.1189)
Inventories/GDP	0.1123 (0.0063)	0.4715 (0.1477)
Public deficit/GDP	0.1001 (0.0103)	0.1574 (0.1302)
Leverage	2.0093 (0.1576)	1.2885 (0.7772)
Bankruptcy rate	0.0336 (0.0044)	0.3001 (0.1817)

Table 3.1: Statistics for selected variables in the two scenarios: cross-simulation mean and standard deviation (in parenthesis).

3.4 Policy experiments

In what follows, we carry out a number of policy experiments to assess the role of different policies and institutional regimes on the macroeconomic outcomes. We run 25 Monte Carlo simulations for each policy experiment, where one or more parameters of the model are exogenously shifted. Mean values from Monte Carlo repetitions are collected in Table 3.2 and compared with the baseline scenario, the one with imitation activity (i.e., $\chi = 0.5$).

Labor market policy. Let us start with a labor market reform aimed at weakening trade unions power. This is captured by a reduction in parameter α governing the wage-productivity elasticity in equation (2.34), i.e., the degree to which the nominal wage responds to a change in productivity. As in Dosi et al. (2010), in the baseline scenario we have $\alpha = 1$, meaning that trade unions are able to fully pass on any increase in productivity to nominal wages. In Experiment 1.1, we set $\alpha = 0.90$.

We find that a weaker labor union is associated with higher mark-ups and profits and has a positive impact on the growth rate of output, leading to a 60% increase in the average GDP level at the last period of simulation. This should not come as a surprise in that in our model R&D investment, which affects the probability to innovate and imitate for K-firms as well as the accumulation of technological knowledge for C-firms, is a function of realized profits, contrary to, for instance, Dosi et al. (2010) and Caiani et al. (2019) where R&D depends on past sales. This makes the relationship between demand, distribution, innovation and growth less trivial. In some sense, using a Post-Keynesian terminology, we can say that in our model growth is profit-led. But this is only a part of the story. In fact, it should be noted that the enhanced output growth comes at the cost of a higher unemployment rate. By fostering the adoption of more efficient techniques, technical progress forces a considerable fraction of workers out of the production process, which is not fully re-absorbed because of the slowdown in wages and demand. The drop in employment, however, does not impair the growth process because the resulting expansion of public deficit meant to finance unemployment subsidies provides support to aggregate demand.[9] To assess the role of fiscal policy in a weak labor union environment we replicate the experiment by shutting off the Government spending on unemployment subsidies. In this case (Experiment 1.2), the economy experiences a collapse in GDP and employment, higher output volatility and, despite the lack of unemployment benefits, an explosion of public deficit due to interest payments on (initial) outstanding bonds and declining tax revenues. Hence, this experiment shows that in presence of weak labor unions fiscal policy is essential to support aggregate demand and guarantee a profit-led growth, otherwise the economy would remain stuck in a high unemployment-low growth trap.

Competition policy. The second experiment aims to analyze the model outcomes in two different market regimes characterized by high and low transaction costs. The purpose is to examine the role of the degree of competition on market structure and overall economic performance. This is captured by turning up and down by one unit the parameters governing the number of firms to be visited on the consumption good market by households ($Z_c = 4, 2$) and on the capital good market by imitators ($Z_{imi} = 5, 3$). Results show that higher (lower) transactions costs imply a lower (higher) GDP, both in terms of growth rate and absolute level, a lower (higher) consumption and a higher (lower) share of unsold goods. In presence of high transaction costs, indeed, firms are visited by fewer households on the C-good market, while the reduced imitation activity slows down technical progress. Interestingly, we find that the a lower degree of competition is associated with a marked decrease in market concentration, as evidenced by the 50 percent shrinkage in the HH index in Experiment 2.1. This is well in tune with the literature (e.g., Dawid et al., 2019; Autor et al., 2020) which points to a strict positive relationship between

[9] Note that, unless specified otherwise, in all policy experiments we keep active the engine of fiscal policy.

Policy experiment	GDP gr.	GDP std.	U	HH	Avg. Mu	Π/GDP	GDP_ly	C/GDP	Inv/GDP	Def/GDP
0. Baseline	0.2453	0.0169	0.0903	168.677	0.0549	0.1915	1	0.8719	0.1123	0.1001
	(0.0006)	(0.0020)	(0.0118)	(0.6895)	(0.0246)	(0.0135)		(0.0074)	(0.0063)	(0.0134)
1. Labor market policy										
1.1 Weak labor union	0.3164	0.0213	0.2692	188.9665*	0.5172	0.2261	1.6486	0.8758*	0.1127*	0.2539
	(0.0004)	(0.0036)	(0.0878)	(0.2823)	(0.4124)	(0.0673)		(0.0345)	(0.0367)	(0.0523)
1.2 Weak labor union + no subsidy	0.0305	0.0197	0.7651	140.595*	0.0611*	0.2749	0.1301	0.9201	0.0568	0.6723
	(0.0006)	(0.0019)	(0.0607)	(0.2235)	(0.0105)	(0.0168)		(0.0128)	(0.0102)	(0.1098)
2. Competition policy										
2.1 High transaction costs	0.1767	0.0134	0.0747	109.601	0.0662*	0.2195	0.4742	0.8487	0.1304	0.1153
	(0.0006)	(0.0021)	(0.0132)	(0.4402)	(0.0201)	(0.0191)		(0.0085)	(0.0044)	(0.0221)
2.2 Low transaction costs	0.3249	0.0206	0.1042	267.922	0.0781	0.1824	1.8011	0.8793	0.1071	0.0935
	(0.0007)	(0.0040)	(0.0234)	(1.1249)	(0.0732)	(0.0198)		(0.0128)	(0.0132)	(0.0126)
3. Innovation policy										
3.1 High knowledge spillovers	0.2791*	0.0174*	0.0929*	206.322*	0.0644*	0.1916*	1.1321*	0.8706*	0.1140*	0.0978*
	(0.0012)	(0.0027)	(0.0171)	(1.8768)	(0.0441)	(0.0195)		(0.0113)	(0.0114)	(0.0161)
3.2 High knowledge spillovers + ex. AC	0.3175	0.0168*	0.0834	166.683*	0.0673	0.2080	1.1975*	0.8697*	0.1107	0.0955*
	(0.0006)	(0.0015)	(0.0099)	(0.6398)	(0.0076)	(0.0156)		(0.0076)	(0.0052)	(0.0131)
4. Fiscal policy										
4.1. Spending constraints	0.1568	0.0274	0.5287	204.886	0.0590*	0.2269	0.2784	0.8271	0.1516	0.1397
	(0.0001)	(0.0036)	(0.0911)	(0.2790)	(0.0098)	(0.0098)		(0.0144)	(0.0137)	(0.0515)

Table 3.2: Cross-simulation mean and standard deviation (in parenthesis) for selected variables under different policy regimes. A two-sample t-test for equal means with respect to the baseline model is performed: the symbol * indicates that the null hypothesis is not rejected. Variables description: *GDP gr.*, growth rate of GDP; *GDP std.* GDP volatility; *U*, unemployment rate; *HH*, Herfindahl-Hirschman index; *Avg. Mu*, weighted-average mark-up; Π/GDP, profit share; *GDP_ly*, GDP level in the last simulation period; *C/GDP*, consumption share; *Inv/GDP*, inventories share; *Def/GDP*, public deficit-GDP ratio.

price competition and market concentration. In our model, in fact, the higher Z_c, the larger the segment of the market visited by consumers, the higher the chances of finding the cheapest goods sold by more productive firms, thus enabling the latter to expand their market shares. In the next section, we examine more thoroughly the relationship between competition, concentration and GDP with or without entry barriers by means of a sensitivity analysis.

Innovation policy. We now want to get further insights on the process of knowledge accumulation, which, as seen in the previous section, plays a fundamental role in the choice of capital vintage, thus influencing the emergence of technological discontinuities and market concentration. First of all, we are going to explore the effects of a change in the degree of intra-industry knowledge spillovers, represented by ψ in equation (2.6). This parameter captures the extent to which other firms' R&D effort affects the accumulation of technological knowledge by the individual firm. In other words, a high value of ψ means that the R&D activity carried out by one firm increases the pool of technological knowledge available to all firms (Cohen and Levinthal, 1989).

In the first high-knowledge spillover policy (Experiment 3.1), ψ is increased from 0.1 (benchmark value) to 0.9. Unsurprisingly, this policy does not entail any significant effect on the model outcomes. This is because, in such a scenario, the ability to exploit outside knowledge spillovers, i.e., the *absorptive capacity*, is still endogenous to firms' R&D experience, as shown in equation (2.7): notwithstanding the availability of technological information, in presence of an endogenous absorptive capacity, smaller firms do not have the necessary technical skills to exploit them, failing to reduce the technology distance from the leaders.

For the sake of completeness, we investigate the effects of the same innovation policy under an institutional regime characterized by exogenous absorptive capacity ($\gamma = 1$). We can think of it as an ideal world in which all firms not only have access to the same pool of technological information, but are also endowed with the necessary technical ability to process them, so that knowledge differentials substantially disappear. In such a scenario (Experiment 3.2), an high-knowledge spillover policy has a positive impact on the economy in terms of lower unemployment and higher output growth, although the last period GDP level is insignificantly different from the benchmark.

The purpose of this simulation exercise is simply to highlight that a top-down innovation policy, if not coupled with alternative measures aimed at directly or indirectly tacking the roots of market concentration and/or compensating for the negative effects it produces on income distribution and aggregate demand, is likely to be ineffective in stimulating economic growth.

Fiscal policy. Finally, similarly to Experiment 1.2, we investigate the impact of a restrictive fiscal policy, but, in this case, in a context of normal labor market regime, i.e., $\alpha = 1$. Differently from the baseline scenario, wherein public budget freely adapts to business fluctuations in a fully anti-cyclical fashion, we introduce a budget constraint that imposes a 3% ceiling on the deficit to GDP ratio: whenever the budget deficit exceeds that threshold, the Government is forced to cut public spending on unemployment subsidies accordingly. Given that in the baseline scenario the (gross) deficit-GDP ratio is around 10%, imposing a budget constraint at 3% is almost equivalent to shutting down the Keynesian engine of fiscal policy. In line with Dosi et al. (2010), we find that a strict budgetary rule would severely harm GDP, aggregate demand and unemployment, leading to an increase in income inequality and concentration in that the reduced aggregate demand would be largely satisfied by a lower number of big firms.

3.5 Can concentration be good for the economy?

The analysis carried out so far suggests that in presence of entry barriers, the process of rising concentration, even if driven by technical progress, has long-lasting detrimental effects on dis-

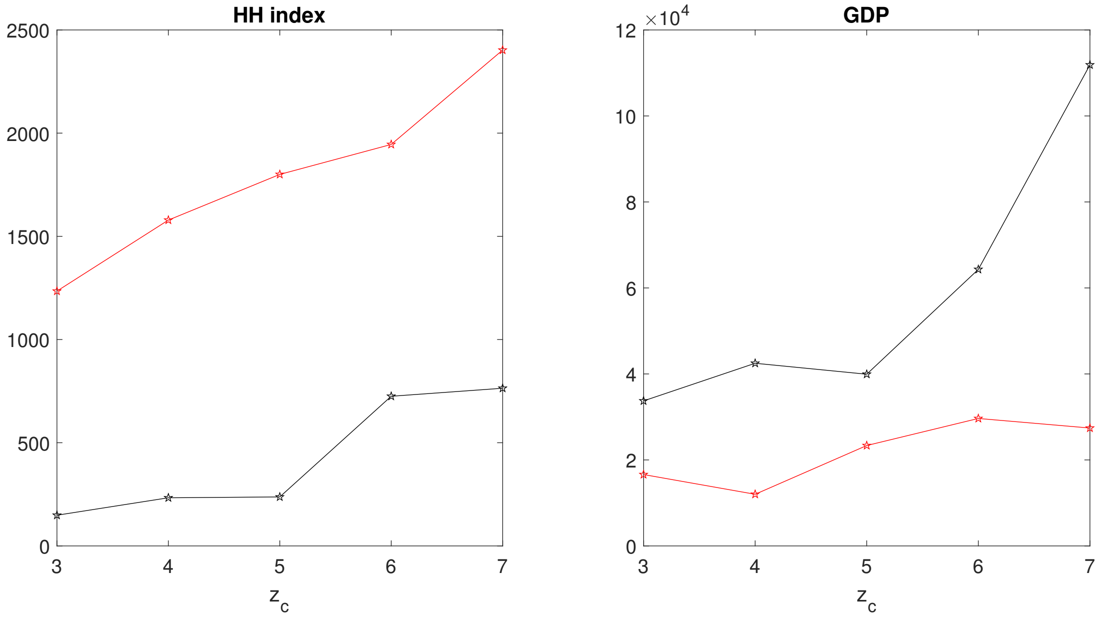


Figure 3.10: Average HH index and GDP level by Z_c under imitation (black) and no-imitation (red) scenario.

tribution and economic growth. The reason is twofold. On the supply side, limited imitation activity in the K-sector, by curbing the diffusion of the best innovations among capital good firms, hampers technical change and productivity growth. On the demand side, greater profit margins stemming from the enhanced marker power cause a progressive shift in the income distribution from wages to profits, which negatively impacts on consumption and aggregate demand.

However, some authors (e.g. Autor et al., 2017, 2020) suggest that rising concentration, when spurred by technical change and product market competition, leads a reallocation of market shares towards more productive firms which ultimately fosters output and productivity growth. Among the causes behind the increase in market competition the authors emphasize the role of improved search technologies which provides a greater availability of price comparisons on the internet (Akerman et al., 2021). According to this view, therefore, market concentration is efficiency-enhancing and has a positive impact on the economy.

The remaining part of this paper aims to investigate whether and under which conditions this hypothesis is verified in the framework of the present model. In particular, we want to analyze the impact of an increase in product market competition, captured by the parameter Z_c, i.e., the number of firms visited by consumers, on concentration and aggregate output and how such a relationship is affected by entry barriers.

For this purpose, we conduct a sensitivity analysis in which we run 25 Monte Carlo simulations for each value of parameter Z_c going from 3 (benchmark case) to 7. To assess the role of entry barriers, we replicate the experiment for the case in which imitation activity is not allowed, i.e., $\chi = 0$. Figure 3.10 plots for each Z_c the corresponding value of HH index and GDP, averaged over time and across simulation runs.

It can be seen that in the imitation scenario (black curve), a higher degree of competition implies a steady growth in market concentration as well as a remarkable increase in total production. By contrast, in presence of legal entry barriers (red curve), as Z_c increases, GDP remains roughly constant in spite of the rising HH index. Therefore, it emerges that whereas in the imitation scenario competition-driven concentration benefits the economy such positive effects are canceled out by the presence of entry barriers and market power.

4 Conclusion

Building on the recent debate on rising concentration, stagnation and inequality (Stiglitz, 2019; Syverson, 2019; De Loecker et al., 2020), this paper aims at exploring the causes and consequences of rising market concentration, by focusing on the interplay of technical change and market power.

Simulation results have shown that, in the short-run, the introduction of new innovations in the market generates a spontaneous wave of concentration in so far as firms with greater accumulated knowledge are able to exploit them, thereby achieving productivity gains and larger market shares. Operating under oligopoly conditions, the emerging "superstar" firms seek to exert the enhanced market power by extracting higher profit margins. As the weight of large firms grows over the economy, the increase in the weighted-average mark-up leads to a shift in the income distribution from wages to profits (Kalecki, 1942), which eventually undermines demand and growth (Keynes, 1936; Steindl, 1976). A stagnation tendency, thus, endogenously arises out of the normal functioning of an oligopoly economy characterized by knowledge-based technical entry barriers. Yet, the dynamics of industry concentration in the long-run is not straightforward. Indeed, further simulation experiments reveal that, whereas the first wave of concentration is triggered by technical entry barriers, which constrain firms' access to technological innovations, the evolution of concentration over time crucially depends on the presence (or lack thereof) of legal entry barriers, which affect the process of diffusion of technological innovations, thereby influencing the firms' ability to consolidate their position and exploit their market power.

From additional policy experiments, we find that labor market reforms aimed at weakening labor unions, by boosting profit margins and innovation, can foster a profit-led growth. Yet, the following slowdown in wages and demand has to be compensated by an anti-cyclical fiscal policy, in the absence of which the economy would remain stuck in a high unemployment-low growth trap. Moreover, while in the absence of entry barriers a reduction of transaction costs may promote a competition-driven concentration which benefits growth, innovation policies geared to spurring knowledge spillovers across firms risk to be ineffective as long as the technical ability to process them remains unequally distributed in a concentrated industry. Finally, a restrictive fiscal policy that prevents a fully anti-cyclical management of the public budget accentuates the stagnation tendency which eventually results in higher concentration, as the reduced demand is largely satisfied by a fewer number of firms.

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Appendices

Appendix A Accounting and balance sheets

In what follows we describe the agents' balance sheets and micro/macro accounting identities of the model.

The balance sheet for C-firms respects the following accounting identity

$$b^k_{it}K_{it} + D_{it} + p_{it}inv_{it} = L_{it} + E_{it}, \tag{A.1}$$

where $b^k_{i,t}K_{i,t}$ is the book value of capital, D_{it} is the firm's deposits, $p_{it}inv_{it}$ is the inventories of C-goods valued at the current price, L_{it} is outstanding debt and E_{it} is equity, or net worth.

C-firms hold cash liquidity in forms of bank deposit, which evolves as follows:

$$D_{it} = D_{it-1} + \pi_{it} + \Delta L_{it} - \theta L_{it} - p_{jt}I_{it} - div_{it} - RD_{it}, \tag{A.2}$$

where π_{it} is the firm's profits, θL_{it} the debt installments, $p_{jt}I_{it}$ is the cost of new capital evaluated at current price of capital goods. div_{it} is the dividend payments.

When the firm's equity turns negative, the firm is bankrupted and exits the market. Then, the owner uses his own wealth to recapitalize her.

For the sake of simplicity, K-firms do not borrow from the bank and employ only labor as input of production. Therefore, the balance sheet of K-firms reads

$$D_{jt} = E_{jt}, \tag{A.3}$$

where their liquidity evolves as follows

$$D_{jt} = D_{jt-1} + \pi_{jt} - div_{jt}. \tag{A.4}$$

Households' wealth E_{ht} coincides with their deposit D_{ht}, which evolves by adding up their income and subtracting the consumption expenditure.

$$E_{ht} = D_{ht}, \tag{A.5}$$

$$D_{ht} = D_{ht-1} + Y_{ht} - C_{ht}. \tag{A.6}$$

As far as the bank is concerned, her balance sheet is given by

$$R^b_t + L_t = D_t + E^b_t, \tag{A.7}$$

where R^b_t are the bank's reserves, L_t are total loans provided to C-firms and the Government, D_t are households' deposits and E^b_t is the bank's net worth.

Bank's profits are the sum of interest payments of N^s_F solvent borrowers, including the Government; there are no costs, since deposits are not remunerated:

$$\pi^b_t = \sum_{s=1}^{N^s_F} r_{st}L_{st} + rB_{t-1}. \tag{A.8}$$

The bank's equity is updated as follows:

$$E_{b,t+1} = E_{bt} + (1 - div_b)\pi_{bt} - BD_t, \tag{A.9}$$

where div_b is the constant fraction of dividends paid by the bank to capitalists. BD_t stands for bad debt, and is the total value of interest payments due by N_F^n insolvent borrowers, i.e. $BD_t = \sum_{n=1}^{N_F^n} L_{nt}$.

The following set of equations illustrate the system of interrelated aggregate balance sheets:

$$R^b = D^H + M^I + M^J + E^B \tag{A.10}$$

$$M^I = D^I - L^I \tag{A.11}$$

$$M^J = D^J - L^J. \tag{A.12}$$

where $M^I = E^I - (K + \Delta)$ and $M^J = E^J - \Delta^J$ are money in the hands of, respectively, C-firms and K-firms.

Appendix B Parameter setting

Symbol	Description	Value
W	Number of workers	2000
F	Number of C-firms	200
N	Number of K-firms	20
Z_c	Number of C-firms visited by consumer	3
Z_u	Number of firms visited by unemployed workers	5
Z_{imi}	Number of K-firms visited by imitators	4
$\bar{l}$	Capital-labor ratio	2
α	Wage-productivity elasticity	1
$\bar{\omega}$	Desired utilization rate	0.85
κ	Desired inventories rate	0.1
ρ	Sales adaptive expectation parameter	0.25
$\{c_y^w, c_y^k\}$	Marginal propensity to consume out of income	{0.80, 0.20}
c_f	Marginal propensity to consume out of wealth	0.05
υ	Unemployment subsidy rate	0.40
$\{\tau^w,\tau^k\}$	Tax rate on labor and capital income	{0.04, 0.02}
div	Firms-bank payout ratio	0.20
δ	Depreciation rate of capital	0.03
δ^{inv}	Depreciation rate of inventories	0.30
δ^z	Depreciation rate of knowledge	0.005
$\sigma^{c,k}$	R&D investment propensity	0.30
χ	R&D allocation between innovation-imitation	0.50
ζ	Search capabilites parameter	0.30
η	Absorptive capacity parameter	0.03
ψ	Degree of knowledge spillovers	0.1
β	Intensity of choice of K-good	30
λ	Intensity of choice of C-good	1
s	unemployment subsidy rate	0.4
r	Refinancing rate	0.01
μ_b	Bank gross mark-up	1.2
β_b	Bank loss parameter	1.2
A_0	Initial value of C-firms productivity	1/3
B_0	Initial value of K-firms productivity	1/2
$\{a_1, a_2\}$	Effective productivity parameters	{1, 1.2}
$(\mu_{FN_1}, \sigma^2 FN1)$	Folded Normal Distribution parameters for product innovation	(0.03, 0.008)
$(\mu_{FN_2}, \sigma^2 FN2)$	Folded Normal Distribution parameters for process innovation	(0.02, 0.008)
$(\mu_{FN_3}, \sigma^2 FN3)$	Folded Normal Distribution parameters for mark-up	(0.02, 0.008)

Table B.1: Benchmark parameter setting