Market Power, Technical Progress and Financial Fragility *

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Abstract

We explore the nexus of market power, innovation and financial fragility by means of a macroeconomic agent based model whose core is a theory of firm behaviour which complements the Dixit-Stiglitz model of monopolistic competition with the Greenwald-Stiglitz characterization of the firm as a borrower that takes into consideration expected bankruptcy costs. In this Dixit-Greenwald-Stiglitz (DGS) setting the optimal firm's size is increasing with net worth and productivity. Net worth increases with profits while productivity increases through R&D and innovation. Simulations show that in the presence of market power firms are more innovative and financially robust and less prone to bankruptcy. These features have not surfaced so far in standard characterizations of monopolistic competition.

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1 Introduction

Richard Day has been a pioneer in the exploration of the ways in which profit seeking firms adapt to a changing environment and try to modify it. His *adaptive evolutionary approach* (Day, 1967a,b, 1971, 1975, 1993) is a source of inspiration for researchers who conceive the economy as a *complex adaptive system* and the firms as agents that exploit market power not only to set prices but also to explore the space of technological opportunities (in order to increase productivity and market share) under the constraint represented by the availability of finance.

Technological advancement and financing constraints interact in both directions. On one hand, a sufficient volume of finance is necessary to fund R&D and boost productivity. On the other hand, changes in productivity impact upon the cost structure, the accumulation of internal finance and the capability of firms to reimburse debt. In the end, in a complex economy *market power, technical progress and financial fragility* are intertwined both at the firm level and in the macroeconomy.

In this paper we explore the nexus of these three essential features of the corporate sector by focusing on monopolistic competitive firms which differ from one another along two profiles: financial robustness, measured by net worth, and innovating capacity, measured by productivity.

Our theory of firm behavior blends the Dixit-Stiglitz model of monopolistic competition (Dixit and Stiglitz, 1977) with bankruptcy costs *à* Greenwald-Stiglitz (Greenwald and Stiglitz, 1993). We label this theory of firm behaviour the Dixit-Greenwald-Stiglitz (DGS) model.

We nest the DGS theory of firm behaviour in a macroeconomic *agent based model* along the lines of Tedeschi et al. (2021) - which in turn is grounded in Delli Gatti et al. (2005) - that is centered around the borrowing-lending relationship that links firms to banks.

In our model DGS firms are continuously searching for opportunities of technical advancement that allow to increase productivity and abate costs. Therefore there are two drivers of change, one for each variable determining the state of the firm, namely productivity and net worth. The state of the firm changes over time because of R&D expenditure, that affects productivity through innovation and because of profit earnings that increase net worth and strengthen the financial position of the firm.

In our model three parameters play a relevant role: the degree of market power measured by the inverse elasticity of demand η, the effort in R&D investment measured by the fraction of revenue spent in research σ and the "patience" or forgiveness of the bank measured by the length of the grace period τ_R granted to defaulting firms.

We consider two scenarios, the *Benchmark* in which firms do not invest in R&D (and therefore do not increase productivity) and the bank does not allow rescheduling and the *Innovate & Reschedule (IR)* scenario in which firms strive to innovate and the bank is forgiving.

We explore two market structure for each scenario: market power ($\eta = 1/4$ corresponding to a markup over marginal cost of approximately 33%) and (almost) perfect competition ($\eta = 0.0001$).

Simulations show two major differences between market power and almost perfect competition. First, in the presence of market power the time series of GDP in the IR scenario lies clearly and consistently above that of GDP in the benchmark for low σ while it lies below the benchmark for high σ. This is not the case in almost perfect competition, whereby GDP in the IR scenario practically overlaps with that in the Benchmark for a wide range of σ and lies below GDP in the Benchmark for σ very high. We conclude that a non-negligible degree of market power is necessary to detect a positive effect of R&D expenditure on GDP at least for low values of σ.

The dynamic pattern changes in nature when τ_R reaches the maximum. In this case GDP in the IR scenario takes off along a growth path for σ sufficiently high. Second, regardless of the numerical values of σ and τ, in the presence of market power the aggregate leverage of the corporate sector and the number of bankrupt firms in the IR scenario is remarkably lower than in the benchmark. Under almost perfect competition, for high σ the benchmark and the IR scenarios produce the same number of bankruptcies. Hence the corporate sector is financially more robust in the IR scenario in the presence of market power.

The paper is organized as follows. In Section 2 we provide a concise overview of the literature. Section 3 is devoted to a description of the model building strategy we adopted. In section 4 we present and discuss the DGS model of firm behaviour in the absence of innovation. In section 5 we extend the DGS model of firm behaviour to introduce R&D spending, innovation and productivity increase. Section 6 describes the behaviour of the bank (for simplicity, in this paper the banking system is represented by a single bank). In section 7 we present the sequence of events on the markets for goods and for credit. Section 8 describes credit arrangements in normal times and in the presence of illiquidity and default, debt rescheduling included. In section 9 we present and comment the results of the simulations. Section 10 concludes.

2 A succinct review of the literature

In the literature, market power, technical progress and financial fragility have been generally dealt with separately or in pairs. The relationship between market power, R&D and technical progress is the focus of Schumpeter's theory of capitalism, which has been the main source of inspiration for a huge literature in industrial organization – see, among many seminal contributions: Arrow (1962), Dasgupta and Stiglitz (1980a,b), Bhatthacharya and Mookherjee (1986) –, the theory of endogenous growth *à* la Aghion and Howitt (Aghion and Howitt, 1992; Aghion et al., 2014) and the evolutionary theory of innovation *à* la Dosi-Nelson-Winter (Nelson and Winter, 1985; Dosi, 1982).

In canonical macroeconomic models with financial frictions, financially constrained firms play a crucial role in business fluctuations but they are not necessarily endowed with market power. For instance, in Bernanke et al. (1999) – by far the most influential early work in this area – "entrepreneurs" enter a borrowing-lending relationship with financial intermediaries to finance the cost of capital. In an environment of ex-post asymmetric information and costly state verification they are charged an interest rate augmented by an external finance premium that is increasing with the firm's leverage. The borrowing-lending relationship between entrepreneurs and banks is the ultimate source of the financial accelerator. Entrepreneurs, however, have no market power. They produce a homogeneous wholesale good under perfect competition. In this model only "retailers" operate under monopolistic competition. They buy homogeneous goods from entrepreneurs and differentiate them to produce varieties to be sold to households and earn a profit margin. Retailers, however, are not financially constrained.

Financially constrained firms endowed with market power that pursue technical progress are key actors in the most recent evolutionary agent based frameworks proposed by Dosi and co-authors (Dosi et al., 2010, 2013) and by Dawid and co-authors (Dawid et al., 2014)). These are the settings closest in spirit to our model. Our modelling strategy, however, is substantially different. We devote the next section to an overview of this strategy.

3 Model building strategy

Our starting point is the canonical model of monopolistic competition developed by Dixit and Stiglitz (Dixit and Stiglitz, 1977), in which each firm faces a downward sloping demand curve and sets the individual price and quantity by equating the marginal revenue and the marginal operating cost. This model captures the essence of market power but is of limited use to explore a complex economy in which firms (i) strive to increase their market share by spending in R&D to access product innovation and increase productivity; (ii) face a financing constraint and strive to survive by validating debt commitments.

We therefore depart from this benchmark first of all by introducing a random shock to demand that brings about uncertainty over the exact position on the price-quantity plane of the demand curve that the firm is facing. Second, we assume that the firm needs finance to cover costs and therefore enters a borrowing-lending relationship. In this uncertain environment the firm runs the risk of bankruptcy, which occurs if there is a sizable negative demand shock. The firm, being aware of the risk of bankruptcy, incurs bankruptcy costs (on top of operating costs) along the lines of Greenwald and Stiglitz (1993).

Profit maximization in this Dixit-Greenwald-Stiglitz (DGS) environment yields the optimal firm's size, which - given the elasticity of demand and therefore the degree of market power - is increasing with productivity and with net worth. The firm-specific combination of productivity and net worth characterizes the *state of the firm*. Firms defined by different states are also heterogeneous in size.

We consider an economy populated by households, firms and a bank. The focus is on the corporate sector, which consists of N_F firms. Households spend all their wage earnings in consumption goods and supply all the labour the firms need (labour supply is abundant). For simplicity, given the focus of this paper, there is only one bank. Each firm asks for a loan at the beginning of a period (year) to fill the financing gap (i.e., the difference between production costs and internal finance) and promises to pay back principal and interest in equal installments in each of a given number of sub-periods (quarters). Hence interest payments are certain (predetermined) while operating profits in each quarter are uncertain.

Total credit supply is limited by prudential capital requirements imposed on the bank by regulators. The interest rate that the bank charges to a borrowing firm is increasing with the borrower's leverage. Firms and the bank make decisions in a complex and uncertain environment in which the interactions among agents may generate synchronized financial distress. Non-linearities due to the cumulative mechanisms of negative and positive feedbacks are pervasive due to these complex interactions. This hallmark of the approach pioneered by Richard Day -see, for instance (Day, 1994, 2000) - is central to models of complex adaptive economies.

At the end of each quarter, a flow of liquidity generated by the sale of goods accrues to the firm. If this flow is positive and big enough to repay debt, the firm fulfills debt commitments. If the flow is negative, a liquidity shortage will occur and the firm will be unable to fulfill debt commitments. Illiquidity therefore leads to default. In the end exit can occur either for excess of liabilities over assets (negative net worth) or for protracted illiquidity.

The key computational device to introduce default due to illiquidity is the differentiation of time scales: the firm makes all the important decisions (the demand for loans included) at yearly frequencies (at the beginning of each year) while sales and interest payments occur at quarterly frequencies.
If the bank stops lending, illiquid firms will not survive and will exit. In this case the bank will experience a loss. If, on the other hand, the bank agrees to restructure debt and keep lending, firms survive and may be able to fulfill interest payments. We assume that banks are willing to reschedule the debt of highly indebted firms that show a potential for innovation. Rescheduling consists in granting additional time for the defaulting firm to reimburse debt. Notice that rescheduling may not be successful. It may well be the case that firms with rescheduled debt will experience again a liquidity shortage in the future, in which case banks will record higher losses.[1]

4 The firm

We consider a population of N_F firms. In this section we describe the simplest setting in which firms do not invest in R&D to increase productivity. We introduce these additional features in section 5.

4.1 Technology and cost structure

The i-th firm, $i = 1, 2, ...N_F$, employs labour N_i and capital K_i to produce output Y_i according to the following Leontief production function:

$$Y_{i,t} = \min\left(\phi_{i,t-1}K_{i,t}, \nu_{i,t-1}N_{i,t}\right) \quad (1)$$

where $\phi_{i,t-1}$ and $\nu_{i,t-1}$ represent the productivities of capital and labour inherited from the past and available in t. We assume Hicks-neutral technical change: the productivity of labour increases at the same rate of that of capital

[1]The literature on illiquidity, financial distress and default is huge. See for instance Moretto and Tamborini (2007), Mosebach (1999), Ongenah and Smith (2000), Gilson et al. (1990).

so that capital intensity does not change over time:[2] $\frac{K_{i,t}}{N_{i,t}} = \frac{\nu_{i,t}}{\phi_{i,t}} = \frac{\nu_{i,t-1}}{\phi_{i,t-1}} = k$. The productivity of capital is firm specific. Hence in every period ϕ_i has a certain probability distribution over a positive support. This distribution evolves over time due to technical progress. Since, by construction, $\nu_{i,t-1} = k\phi_{i,t-1}$, also the productivity of labour has a probability distribution over a positive support. We assume that labour is abundant so that we can write $Y_{i,t} = \phi_{i,t-1}K_{i,t}$. Hence employment is $N_{i,t} = \frac{K_{i,t}}{k} = \frac{Y_{i,t}}{k\phi_{i,t-1}}$.

Let's denote with w the real wage (uniform across firms) and with $gr_{i,t}$ the firm-specific user cost of capital, where $r_{i,t}$ is the real interest rate on loans extended to the i_th firm and $g > 1$. Total *operating* or production costs in real terms therefore are

$$C_{i,t} = \gamma_{i,t}K_{i,t} = \frac{\gamma_{i,t}}{\phi_{i,t-1}}Y_{i,t}$$

where $\gamma_{i,t} := \frac{w_t}{k} + gr_{i,t}$ is the (operating) cost per unit of capital and

$$c_{i,t} := \frac{\gamma_{i,t}}{\phi_{i,t-1}} \tag{2}$$

is the (average and) marginal operating cost. *Operating profits*, i.e., total revenues net of total operating costs are

$$\pi_{i,t} = p_{i,t}Y_{i,t} - c_{i,t}Y_{i,t} \tag{3}$$

4.2 Debt and the risk of bankruptcy

We assume that firms produce differentiated goods (varieties) in a monopolistic competition setting à la Dixit-Stiglitz. The market demand for the i-th variety is: $Y_{i,t} = p_{i,t}^{-\varepsilon}u_{i,t}^{\varepsilon}$ where $p_{i,t} := \frac{P_{i,t}}{P_t}$ is the relative price, $\varepsilon \in (1, \infty)$ is the absolute value of the price elasticity of demand and $u_{i,t}$ is a stochastic demand shock with $E(u_{i,t}) = 1$ and finite variance. The inverse demand function therefore is

$$p_{i,t} = Y_{i,t}^{-\eta}u_{i,t} \tag{4}$$

[2]For simplicity we assume that capital intensity is uniform across firms.

where $\eta := \frac{1}{\varepsilon}$ is the inverse elasticity. By construction $\eta \in (0, 1)$. Revenues and operating profits are stochastic because of the randomness of $u_{i,t}$. Taking into account (3), and (4) we can write operating profits as follows:

$$\pi_{i,t} = u_{i,t} Y_{i,t}^{1-\eta} - c_{i,t} Y_{i,t} \tag{5}$$

Since the demand function is subject to a shock, the actual price $p_{i,t}$ may be different from the expected price $E(p_{i,t}) = Y_{i,t}^{-\eta}$, i.e., the price at which the firm expects to sell its goods. Hence expected revenue is $E(p_{i,t})Y_{i,t} = Y_{i,t}^{1-\eta}$. Expected operating profits are:

$$E(\pi_{i,t}) = Y_{i,t}^{1-\eta} - c_{i,t} Y_{i,t} \tag{6}$$

Let's assume that internal finance is insufficient to cover operating costs - i.e., the firm has a financing gap. In this case, the firm will ask a loan to a bank and therefore will run the risk of bankruptcy. This occurs when

$$A_{i,t-1} < c_{i,t} Y_{i,t} \tag{7}$$

where A_i is net worth or the equity base. In this setup - borrowed from Greenwald-Stiglitz - the firm incurs bankruptcy costs on top of operating costs. To quantify the risk of bankruptcy, notice first that the firm accumulates net worth by means of profits.[3] Net worth, therefore, evolves according to

$$A_{i,t} = A_{i,t-1} + \pi_{i,t}. \tag{8}$$

Because of the uncertainty surrounding profits (due to the random shock u_i), the firm may go bankrupt. Bankruptcy occurs if net worth becomes negative $A_{i,t} < 0$, that is – recalling the definition of operating profits (5) – if

$$u_{i,t} < \frac{c_{i,t} Y_{i,t} - A_{i,t-1}}{Y_{i,t}^{1-\eta}} \equiv \overline{u}_{i,t}. \tag{9}$$

[3]To be precise, only retained profits enter the law of motion of net worth. For simplicity, we assume that firms do not distribute dividends.

If the realization of the price shock turns out to be smaller than the cut-off value $\overline{u}_{i,t}$, then the firm goes bankrupt. The cut-off value in turn is the ratio of the size of the financing gap (the excess of operating cost over internal financial resources) to total revenue. Assuming that $u_{i,t} \sim U(0, 2)$, the probability of bankruptcy for the i-th firm is:

$$P^b_{i,t} = \frac{\overline{u}_{i,t}}{2} = \frac{c_{i,t}Y_{i,t} - A_{i,t-1}}{2Y^{1-\eta}_{i,t}}$$

Using the production function and recalling the definition of marginal operating cost (2), after some algebra we get:

$$P^b_{i,t} = \frac{K^\eta_{i,t}}{2\phi^{1-\eta}_{i,t-1}} \left(\gamma_{i,t} - \frac{A_{i,t-1}}{K_{i,t}} \right) = \frac{Y^\eta_{i,t}}{2\phi_{i,t-1}} \left(\gamma_{i,t} - \phi_{i,t-1} \frac{A_{i,t-1}}{Y_{i,t}} \right) \tag{10}$$

The probability of bankruptcy is decreasing with productivity and with net worth and is increasing with size (measured by output or capital).[4]

4.3 The financially constrained optimum

Following Greenwald and Stiglitz, we assume that the problem of the firm in the presence of bankruptcy risk consists in maximizing *expected profits* Γ_i, defined as the difference between expected *operating* profits and bankruptcy costs, i.e., legal, administrative and reputational costs incurred during the bankruptcy procedure. Bankruptcy costs are assumed to increase with the firm's size. We assume that bankruptcy costs are quadratic: $C^b_{i,t} = bY^2_{i,t}$ with b a positive parameter uniform across firms. Hence the objective function is

$$\Gamma_{i,t} = E(\pi_{i,t}) - P^b_{i,t} bY^2_{i,t} \tag{11}$$

While Greenwald and Stiglitz assume perfect competition, we consider a monopolistic competition setting. Plugging expected operating profit under monopolistic competition (6) and the probability of bankruptcy (10) in (11)

[4]The firm's size can be measured by output, capital or labour. Each of these variables is proportional to any of the other two variables thanks to Leontief technology. Hence the probability of bankruptcy can be expressed also as a function of employment.

and recalling (2) we get

$$\Gamma_{i,t} = Y_{i,t}^{1-\eta} - \frac{\gamma_{i,t}}{\phi_{i,t-1}} Y_{i,t} - \frac{Y_{i,t}^{\eta}}{2\phi_{i,t-1}} \left(\gamma_{i,t} - \phi_{i,t-1} \frac{A_{i,t-1}}{Y_{i,t}} \right) b Y_{i,t}^{2} \tag{12}$$

The problem of the financially constrained firm in monopolistic competition therefore is $\max_{Y_{i,t}} \Gamma_{i,t}$ with $\Gamma_{i,t}$ defined in (12).

The first derivative of $\Gamma_{i,t}$ with respect to $Y_{i,t}$ is

$$\Gamma_{Y_i} = \underbrace{(1-\eta)\, Y_{i,t}^{-\eta}}_{MR_{i,t}} - \underbrace{\frac{\gamma_{i,t}}{\phi_{i,t-1}}}_{c_{i,t}} - \underbrace{\frac{b}{2} \left[\frac{\gamma_{i,t}}{\phi_{i,t-1}} (2+\eta)\, Y_{i,t}^{1+\eta} - A_{i,t-1} (1+\eta)\, Y_{i,t}^{\eta} \right]}_{b_{i,t}} \tag{13}$$

The FOC for the solution of the maximization problem is $\Gamma_{Y_i} = 0$. The stationary values of $\Gamma_{i,t}$ therefore are the zeros of Γ_{Y_i}. The FOC can be interpreted, as usual, as stating that the Marginal Revuenue $MR_{i,t} = (1-\eta) Y_{i,t}^{-\eta} = (1-\eta) E(p_{i,t})$ must be equal to the Marginal Cost $MC_{i,t}$ but in the case of the financially constrained firm the marginal cost is the sum of the marginal operating cost $c_{i,t}$ and the marginal bankruptcy cost $b_{i,t}$. In symbols:

$$(1-\eta)\, E(p_{i,t}) = MC_{i,t} = c_{i,t} + b_{i,t} \tag{14}$$

For the indebted firm, from (7) follows that $b_{i,t}$ is positive and increasing with $Y_{i,t}$ while $c_{i,t}$ does not depend on output.

Since Γ_{Y_i} is non linear and in principle non monotonic, there can be more than one zero of this function (i.e., there can be multiple local maxima and minima of Γ_i) depending on the numerical values of the parameters and on the levels of the exogenous variables.

4.4 Closed-form solution

The model of firm's behaviour described in the previous section cannot be solved analytically. The optimal price and quantity can be obtained only numerically for a given set of parameters. Building an agent based model – i.e., tracking the behaviour of a large number of heterogeneous firms over time

– on this basis would be a computational nightmare. We therefore simplify the model by linearizing the revenue function in order to obtain a closed form solution which can easily be implemented in an agent based model.

We take a first order approximation of total revenue at the level of output $Y_i = 1$ which is associated with $p_i = 1$. We get

$$Y_{i,t}^{1-\eta} \approx \eta + (1-\eta)\, Y_i \tag{15}$$

Hence we can rewrite the condition for bankruptcy (9) as follows:

$$u_{i,t} < \frac{c_{i,t} Y_{i,t} - A_{i,t-1}}{\eta + (1-\eta)\, Y_{i,t}} \equiv \overline{u}_{i,t}. \tag{16}$$

To simplify computations, we ignore the intercept of the linearized revenue function in the denominator of (16) (with a minimal loss of generality for low values of the inverse elasticity). Using (2), the approximated probability of bankruptcy therefore is:

$$P_{i,t}^{b} = \frac{\overline{u}_{i,t}}{2} = \frac{1}{2\,(1-\eta)} \left(\frac{\gamma_{i,t}}{\phi_{i,t-1}} - \frac{A_{i,t-1}}{Y_{i,t}} \right) \tag{17}$$

In the linearized setting, thanks to (15), the expected operating profit is linear in output:

$$E(\pi_{i,t}) = \eta + \left[(1-\eta) - \frac{\gamma_{i,t}}{\phi_{i,t-1}} \right] Y_{i,t} \tag{18}$$

Using (18) and (17) we get a quadratic objective function:

$$\Gamma_{i,t} = \eta + \left[(1-\eta) - \frac{\gamma_{i,t}}{\phi_{i,t-1}} \right] Y_{i,t} - \frac{1}{2\,(1-\eta)} \left(\frac{\gamma_{i,t}}{\phi_{i,t-1}} - \frac{A_{i,t-1}}{Y_{i,t}} \right) b Y_{i,t}^{2} \tag{19}$$

The first derivative of $\Gamma_{i,t}$ wrt $Y_{i,t}$ is

$$\Gamma_{Y_i} := \underbrace{1-\eta}_{MR_{i,t}} - \left[\underbrace{\frac{\gamma_{i,t}}{\phi_{i,t-1}}}_{c_{i,t}} + \underbrace{\frac{b}{2\,(1-\eta)} \left(\frac{\gamma_{i,t}}{\phi_{i,t-1}} 2Y_{i,t} - A_{i,t-1} \right)}_{b_{i,t}} \right] \tag{20}$$

The FOC for the solution of the problem is $\Gamma_{Y_i} = 0$. Notice that, thanks to the linearization, the marginal bankruptcy cost is a *linear* increasing function of output. Therefore Γ_{Y_i} is linear and decreasing with $Y_{i,t}$ (the objective function is concave), which guarantees that there is only a stationary point and this point is a maximum.

Thus, desired output is

$$Y_{i,t} = \frac{(1-\eta)^2 \phi_{i,t-1}}{b\gamma_{i,t}} - \frac{1-\eta}{b} + \frac{\phi_{i,t-1}}{2\gamma_{i,t}} A_{i,t-1}. \tag{21}$$

and desired capital is

$$K_{i,t} = \frac{(1-\eta)^2}{b\gamma_{i,t}} - \frac{1-\eta}{b\phi_{i,t-1}} + \frac{A_{i,t-1}}{2\gamma_{i,t}} \tag{22}$$

In the optimum output and capital are increasing functions of net worth and of productivity.[5]

By construction, in the linearized setting, in the optimum $MR_{i,t} = (1-\eta)$. Since, by definition, in monopolistic competition $MR_{i,t} = (1-\eta)\,E(p_{i,t})$, we conclude that $E(p_{i,t}) = 1$. The actual relative price therefore coincides with the shock: $p_{i,t} = u_{i,t}E(p_{i,t}) = u_{i,t}$.

4.5 GDP, effective demand and inventories

In a "macroeconomics from the bottom up" perspective, aggregate output (GDP) is obtained by summing production – determined as in (21) – across

[5] In order to assure that optimal output is a positive quantity, we assume that the following inequality holds: $\phi_{i,t-1} > \frac{2(1-\eta)\gamma_{i,t}}{2(1-\eta)^2 + bA_{i,t-1}}$

firms:

$$GDP_t = \sum_{i=1}^{N_F} Y_{i,t} \tag{23}$$

We assume that households spend the entire wage bill in consumption goods:

$$C_t = w_t \sum_{i=1}^{N_F} \frac{Y_{i,t}}{\nu_{i,t-1}}$$

Individual investment is $I_{i,t} = K_{i,t} - K_{i,t-1}$ where $K_{i,t}$ is given by (22). Hence aggregate investment is

$$I_t = \sum_{i=1}^{N_F} \left(K_{i,t} - K_{i,t-1}\right)$$

In our closed economy, aggregate demand is the sum of consumption and investment $Z_t = C_t + I_t$. As customary in ABMs, we do not impose equilibrium of demand and supply on the goods market. Disequilibria $(GDP_t - Z_t)$ show up as involuntary inventories or queues of unsatisfied consumers (not modelled). Of course, equilibrium can occur but, in the absence of a top-down coordinating mechanism, only by chance.

5 R&D expenditure and productivity

In this section we extend the DGS model of firm's behaviour outlined so far in order to take into account R&D and innovation. Firms invest in R&D in order to implement process innovation and increase productivity. Following a consolidated tradition in evolutionary ABMs we assume that expenditure in R&D is a given fraction of the firm's revenue: $R\&D_{i,t} = \sigma p_{i,t} Y_{i,t}$ where $\sigma \in (0,1)$ is R&D *intensity*. By assuming that intensity is exogenous, we implicitly model the decision to invest in R&D as a simple heuristic: the bigger the market of a given firm, i.e., the demand for the goods it produces, the bigger R&D expenditure. By assuming that intensity is uniform across firms, we implicitly assume that bigger firms in terms of revenue invest more in R&D.[6]

We must therefore slightly modify the setting of section 4.3 by introducing an additional expenditure, namely R&D, and an additional parameter, σ. The definition of operating profit becomes:

$$\pi_{i,t} = u_{i,t} \left[\eta + (1-\eta) Y_{i,t}\right] (1-\sigma) - c_{i,t} Y_{i,t} \tag{24}$$

Net worth evolves according to (8) and bankruptcy occurs if $A_{i,t} < 0$. Therefore we can determine a new cut-off value of the price shock:

$$u_{i,t} < \frac{c_{i,t} Y_{i,t} - A_{i,t-1}}{(1-\sigma)\left[\eta + (1-\eta) Y_{i,t}\right]} \equiv \overline{u}_{i,t} \tag{25}$$

Recalling (2) and simplifying the expression in brackets in the denominator we get the probability of bankruptcy:

$$P^b_{i,t} = \frac{1}{2(1-\sigma)(1-\eta)} \left(c_{i,t} - \frac{A_{i,t-1}}{Y_{i,t}} \right) \tag{26}$$

The firm's expected profit in the presence of R&D expenditure is

$$\Gamma_{i,t} = \eta(1-\sigma) + \left[(1-\eta)(1-\sigma) - c_{i,t}\right] Y_{i,t} - \frac{1}{2(1-\eta)(1-\sigma)} \left(c_{i,t} - \frac{A_{i,t-1}}{Y_{i,t}} \right) b Y^2_{i,t} \tag{27}$$

From the maximization of $\Gamma_{i,t}$ we get:

$$Y_{i,t} = \frac{(1-\sigma)^2(1-\eta)^2}{c_{i,t} b} - \frac{(1-\sigma)(1-\eta)}{b} + \frac{A_{i,t-1}}{2c_{i,t}} \tag{28}$$

[6] An extensive overview of the recent empirical evidence on R&D spending, with special reference to the European landscape (Grassano et al., 2022), shows that the heterogeneity of intensity across sectors is non-negligible but also non-sizable and – even more important – the dispersion across firms within each sector is small. The average intensity across 11 sectors in 2021 was approximately 4.7%, with a coefficient of variation of 0.78. Among the top 20 companies, however, 8 firms belonging to the automobiles industry spent on average 6% of their revenues in R&D, with a coefficient of variation of 0.19 only.

and recalling the definition of $c_{i,t}$ in (2):

$$K_{i,t} = \frac{(1-\sigma)^2(1-\eta)^2}{\gamma_{i,t} b} - \frac{(1-\sigma)(1-\eta)}{b\phi_{i,t-1}} + \frac{A_{i,t-1}}{2\gamma_{i,t}} \tag{29}$$

Let us now describe the dynamics of the firm's capital productivity, $\phi_{i,t}$ in relation with R&D expenditure.

The outcome of R&D is uncertain. Therefore the firm that has invested in R&D may not succeed in accessing innovation. Whether the firm's R&D expenditure results in a successful innovation or not is determined by a Bernoulli distribution. The probability of success is

$$P^s_{i,t} = 1 - \exp(-\delta z_{i,t}), \tag{30}$$

where δ is a positive parameter and $z_{i,t} = \frac{R\&D_{i,t}}{K_{i,t}}$ is the *propensity to invest in R&D*. The propensity to invest is R&D expenditure per unit of capital used in production. Substituting the definition of R&D in the equation above, we get: $z_{i,t} = \sigma u_{i,t}\left[\frac{\eta}{K_{i,t}} + (1-\eta)\phi_{i,t-1}\right]$. Hence, the propensity to invest $z_{i,t}$ does not coincide with intensity σ and is firm-specific. R&D per unit of capital is increasing with σ, the idiosyncratic price shock $u_{i,t}$ and the productivity of capital $\phi_{i,t-1}$ but is decreasing with the stock of capital $K_{i,t}$.[7] Other things being equal, bigger size (measured by the capital stock) translates into bigger R&D effort, but a smaller propensity to invest in R&D (see Vitali et al. (2013); Grilli et al. (2014) for a similar approach).

If the firm actually access innovation, the law of motion of the firm's productivity will be

$$\phi_{i,t} = (1 + \zeta_{i,t})\phi_{i,t-1}, \tag{31}$$

where the rate of growth $\zeta_{i,t}$ is a random variable uniformly distributed on the support $[\xi_1, \xi_2]$, $0 < \xi_1, < \xi_2$.

[7] The relationship between the propensity to invest and market power η depends on size.

6 The bank

For simplicity we assume that there is only one bank. The bank's balance sheet identity is: $L_t^s = A_{b,t} + D_t$, where L_t^s is total credit supply (i.e., the sum of all the loans the bank has extended to all the firms), $A_{b,t}$ is the bank's net worth and D_t are deposits.

We assume that the bank is willing to lend as much as possible, within the limits set by regulatory authorities. Hence total credit supply is a multiple of the bank's net worth:

$$L_t^s = \frac{A_{t-1}^b}{\alpha}, \tag{32}$$

where $\alpha \in (0, 1)$ is set by prudential regulators as in Basel I and II. According to Basel I, for instance, $\alpha = 0.08$ so that the bank's leverage is constrained to be not higher than $1/\alpha = 12.5$. Credit is allotted to each firm according to its relative size, i.e., the ratio of the firm's current equity base to the total net worth of the corporate sector. Larger firms, therefore, have access to a larger fraction of credit supply.

Each firm is willing to borrow only the amount needed to reach the desired scale of activity. Moreover we assume that the firm keeps a liquidity buffer proportional to capital: $M_{i,t} = mK_{i,t}$ where $m \in (0, 1)$. The firm's fundamental balance sheet identity therefore is $K_{i,t}(1 + m) = A_{i,t} + L_{i,t}$. Consequently, the flow demand for credit is: $L_{i,t} - L_{i,t-1} = (1 + m)I_{i,t} - \pi_{i,t}$.[8] It may well be the case, therefore, that credit supplied to a given firm is greater or smaller than the amount demanded by that firm. In the former case, the firm sets output at the desired level and the available credit line is underutilized; in the latter case, the firm is forced to downsize production to adjust it to the level of funding obtained.

We assume that the interest rate charged by the bank to a single firm depends on the firm's leverage according to the following equation:

$$r_{i,t} = \beta \frac{L_{i,t}}{A_{i,t}}. \tag{33}$$

[8] By definition, the investment of the i-th firm is $I_{i,t} = K_{i,t} - K_{i,t-1}$ where $K_{i,t}$ is given by (29). From (8) follows that $\pi_{i,t} = A_{i,t} - A_{i,t-1}$.

where $\beta \in (0, 1)$ The bank's profit is the difference between the aggregate return on loans and the remuneration of depositors and the bank's shareholders:

$$\pi_{b,t} = \sum_{i \in V_{b,t}} r_{i,t} L_{i,t} - \bar{r}_t (D_t + A_{b,t}) \tag{34}$$

where $V_{b,t}$ is the set of firms borrowing from the bank and $\bar{r}$ is the average interest rate charged to them. In words, depositors (and the bank's shareholders) are remunerated at a rate which is equal to the average interest rate charged to borrowing firms.

Profits are accumulated to increase net worth. Hence the equity base of the bank obeys the following law of motion:[9]

$$A_{b,t} = A_{b,t-1} + \pi_{b,t} - BD_t \tag{35}$$

where BD_t is "bad debt", i.e., the sum of bank losses due to the bankruptcy of a subset of borrowing firms.

7 Market protocol

Actions take place at different time scales. Production and all the associated decisions (capital and demand for credit) are taken *at the beginning of the period*, which is denoted with t (for instance, a year). Each period is, then, divided in n sub-periods denoted with τ (for instance, if the period is a year and $n = 4$, each sub-period is a quarter). In each sub-period τ:

- A fraction $\frac{1}{n}$ of annual output $Y_{i,t}$ (see equation (28) becomes available for sale: $Y_{i,\tau} = \frac{Y_{i,t}}{n}$.
- The market for goods opens. The relative price of the goods produced by the i-th firm is affected by the shock $u_{i,\tau}$. As a consequence, the firm's revenue in real terms in each sub-period is $R_{i,\tau} = u_{i,\tau}\left[\eta + (1-\eta)Y_{i,\tau}\right]$.

[9]From the credit supply equation, the balance sheet identity and the law of motion of the equity base follows $D_t = A_{b,t-1}(\frac{1}{\alpha} - 1) - \pi_{b,t} - BD_t$. Deposits are determined residually.

- The firm spends a fraction of revenue for research and development: $R\&D_{i,\tau} = \sigma R_{i,\tau}$.

- The firm pays the wage bill $W_{i,\tau} = \frac{w_t}{n} \frac{Y_{i,t}}{k\phi_{i,t-1}}$.

- An installment of interest and dividend payments is due: $\rho_{i,\tau} = \frac{g}{n} r_{i,t}(L_{i,t} + A_{i,t})$.

Thus, the sub-period *liquidity flow* generated by profits is:

$$\pi_{i,\tau} = (1 - \sigma)R_{i,\tau} - W_{i,\tau} - \rho_{i,\tau}. \tag{36}$$

8 Credit arrangements

At the end of period t, if the sum of sub-period flows of liquidity: $\pi_{i,t} = \sum_{\tau=1}^{n} \pi_{i,\tau}$ is positive, the firm accumulates net worth (see (8)).

If the firm has experienced a loss in the period ($\pi_{i,t} < 0$) but is still technically solvent – i.e., if the size of the loss is smaller than the equity inherited from the past $|\pi_{i,t}| < A_{i,t-1}$ – then it depletes cash holdings ($M_{i,t}$) to service interest payments. If pre-existing cash holdings are not large enough to cover interest payments, then the firm is unable to service debt and therefore it is formally in default. We assume than in case of firm's default, the bank may propose a credit arrangement to allow the firm survive and possibly restore the capability of validating debt commitments.

Rescheduling plans are frequently employed when firms are unable to fulfill their current obligations and violate debt covenants (Dichev and Skinner, 2002; Smith Jr, 1993). Several studies document the critical role played by the bargaining power of firms in forcing banks to negotiate the resolution of episodes of financial distress: large, highly leveraged firms tend to wield greater bargaining power gaining a comparative advantage (over smaller firms) in reaching settlements with their creditors. This advantage stems from the potential impact their bankruptcy could have on the financial institution involved (Denis and Rodgers, 2007): the bigger the exposure of the bank to a given firm, the bigger the loss in case of insolvency.[10]

[10] A large literature has brought to the fore the systemic repercussions of the bankruptcy

Moreover the empirical literature has documented the willingness of financial intermediaries to support firms that show a substantial capacity for innovation (Chava, 2014). These forward-thinking firms enjoy a wide range of financial advantages, including lower interest rates, enhanced credit facilities, and more favorable credit terms (Fard et al., 2020). To take these empirical regularities into account we assume that the bank follows a two step procedure to pick the defaulting firms who deserve to be rescued.

First, the bank ranks firms according to their willingness to innovate, measured by the level of R&D expenditure $R\&D_{i,t} = \sigma u_{i,t}[\eta + (1-\eta)\phi_{i,t-1}K_{i,t}]$. The innovative effort, therefore, depends on two uniform parameters (R&D intensity σ and the degree of market power η) and on three firm specific components: the idiosyncratic price shock, the firm's capital and its past productivity. In the eyes of the bank a firm has a "low" (respectively: "high") *willingness to innovate* if its R&D expenditure is lower (higher) than the median of all the firms' R&D expenditures.

Second, the bank ranks the firms that experienced a loss in the period (whose set has cardinality N_L) according to the size of the loss. To define a threshold the bank computes the *Relative Loss (RL)*, i.e., the ratio of the size of the individual loss to the minimum loss experienced in the economy: $RL_{i,t} = \frac{|\pi_{i,t}|}{\min(|\pi_{f,t}|)}$, $f = 1, 2, ..., N_L$. In each period, there will be a distribution of relative losses. A firm has a "low" (respectively: "high") relative loss in the eyes of the bank if its relative loss is lower (higher) than the median of all the firms' relative losses.

If the defaulting firm has a high willingness to innovate and a large loss, the bank will adopt a *debt rescheduling* plan which consists in allowing the firm to postpone reimbursement: the bank concedes a *grace period* of length τ_R (measured in number of sub-periods of $t+1$) to the defaulting firm. In other words, the bank sets the maximum number of sub-periods $\tau_R \in [1, n]$) she is willing to forgo interest payments in period t+1. This is a measure of the bank's "patience" or tolerance: the higher τ_R, the more "patient" or forgiving or tolerant the bank is.

of a key firm/borrower (Kaufman and Scott, 2003; Schwarcz, 2008) but usually this consideration does not enter the rescheduling decisions of individual lenders.

At the end of $t+1$, the bank checks again the financial situation of the firm. If the firm has not fulfilled debt commitments within τ_R subperiods, the bank does not provide credit any longer, forcing the firm to exit. Thus, the firm exits when either one of the following two conditions occurs:

- assets fall short of liabilities: $A_{i,t} < 0$;
- the firm experiences a stream of subperiod losses and the bank – possibly after rescheduling – concludes that the firm is doomed. In this case, the firm goes bankrupt because of a persistent liquidity shortage.

The firms exiting in t are replaced in $t+1$ by new firms endowed with an equity level equal to their initial condition.

9 Simulation results

We run simulations of the model for $T = 1000$ periods. Each period denoted with t (a year) is divided into $n = 4$ sub-periods (quarters). Each subperiod is denoted with τ.

There are $N_F = 100$ firms. Each firm is initially endowed with the same amount of capital $K_0 = 5$, financed by means of equity $A_0 = 1$ and bank loans $L_0 = 4$. The bank is endowed with net worth $A_{b,0} = 32$. Initially the bank extends loans $L_{b,0} = 400$ (so that the aggregate demand for loans $L_0 N_F$ is equal to aggregate supply). Initial deposits therefore are $D_0 = 368$.

The model has 11 parameters (uniform across firms). We set and keep fixed the following 7 parameters: $g = 1.1$, $w = 0.005$, $k = 1$, $\delta = 2$, $b = 1$, $\alpha = 0.08$, $\beta = 0.02$, $m = 0.03$. The first three parameters are calibrated so as to obtain zero expected profits in a scenario of perfect competition and no investment in R&D. Moreover, $\delta = 2$ ensures that the probability of innovation generated by Bernoulli (see Eq. 30) is approximately in line with the empirical evidence (3-4%) (Grassano et al., 2021). The parameter $\alpha = 0.08$ is set by prudential regulators as in Basel I and II in such a way that bank's leverage does not exceed $1/\alpha$ =12.5. Finally β in equation 33 guarantees the minimum interest rate of 2%.

We explore the parameter space consisting of the remaining 3 parameters (η, τ_R and σ) on a grid of two numerical values for η, four numerical values for τ_R and six numerical values for σ.

We consider two market structures: (i) a monopolistic competition setting characterized by "high" market power ($\eta = 1/4$); (ii) a market structure characterized by "almost zero" market power, practically indistinguishable from perfect competition ($\eta = 1/10000$). For each of the two market structure we explore two scenarios:

- the *Benchmark* (no-innovation/no-rescheduling) scenario where firms do not invest in R&D ($\sigma = 0$) and cannot rely upon debt rescheduling in case of default ($\tau_R = 0$);
- the *Innovation and Rescheduling (IR)* scenario in which firms spend $\sigma > 0$ of their revenue in R&D and the bank grants a grace period $\tau_R > 0$ to defaulting firms that fulfill rescheduling requirements. In this scenario we run simulations for 6 different values of R&D intensity ($\sigma = \{0.01, 0.02, 0.04, 0.06, 0.08, 0.1\}$) and for 4 different durations of the grace period ($\tau_R = \{1, 2, 3, 4\}$).

9.1 Market power

Let us first study the impact of market power on aggregate variables. In Figure 1 we show the dynamics of GDP in the presence of monopolistic competition and a relatively high degree of market power ($\eta = 1/4$ corresponding to a mark up over marginal cost of 33%) in the benchmark and IR scenarios (black dashed and blue solid line, respectively). We explore all the combinations of the numerical values of σ and τ_R, thereby generating 24 panels.

As expected in macro ABMs, GDP fluctuates irregularly. In the benchmark, GDP fluctuates around a stationary long run mean (quasi-steady state for short). Also in the IR scenario GDP is generally stationary in the long run with the exception of the last two panels which clearly show an upward trend We extract a number of stylized fact from the dynamics of artificial time series generated by simulations.

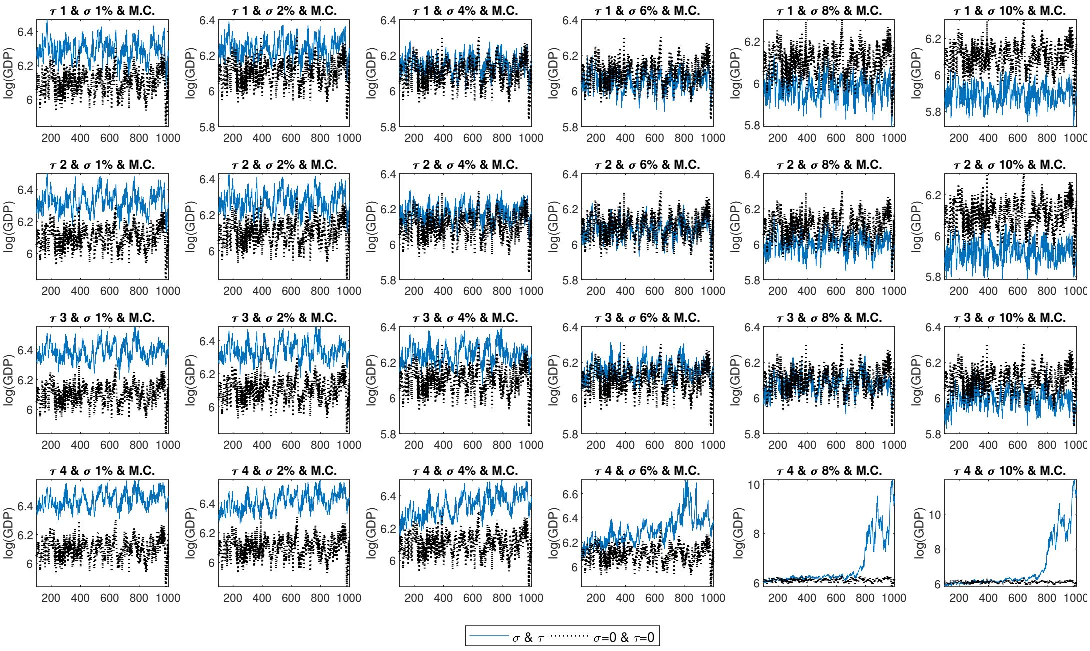

Figure 1: Time evolution of GDP generated by a single simulation in the presence of market power ($\eta = 1/4$) in (i) the Benchmark scenario (no R&D and no rescheduling) (black dashed line) and in (ii) the IR scenario with R&D expenditure (for $\sigma = 0.01, 0.02, 0.04, 0.06, 0.08, 0.1$) and debt rescheduling (for $\tau_R = 1, 2, 3, 4$) (blue solid line). The black dashed line is the same in all the panels. The blue solid line changes depending on the parameterization. Rows (columns) are ordered by increasing levels of τ_R (σ).

Fact 1 *For $\tau_R < 4$, the time series of GDP in the IR scenario in figure 1: (a) lies above that of GDP in the benchmark for $\sigma \leq 0.02$; (b) overlaps with the benchmark for $0.02 < \sigma \leq 0.08$ and (c) lies below the benchmark for $0.08 < \sigma \leq 0.1$.*

The explanation of this fact is straightforward. R&D expenditure has two contrasting effects on the firm's costs and output decisions. On one hand, by definition it has a direct positive effect on costs and negative impact on output. On the other hand, inasmuch as R&D allows to access innovation and translates into an increase in productivity, it has a negative indirect effect on the marginal cost and a positive impact on output. For low (respectively: high) levels of σ the latter (former) effect prevails so that GDP is higher (lower) than in the benchmark. The cut-off value of σ – i.e., the propensity to invest in R&D such that aggregate output generated in the IR scenario overlaps with GDP in the benchmark – is approximately $\hat{\sigma} = 0.05$

Fact 2 *The dynamic pattern in Fact 1 changes in nature when $\tau_R = 4$. In this case GDP in the IR scenario is greater than in the benchmark for any σ and takes off along a growth path for $\sigma > 0.06$ (blue solid line in the fourth row of fig.1).*

For GDP to grow over the long run, therefore, it is necessary a very high propensity to invest in R&D ($\sigma > 0.06$) and a very high propensity of the bank to tolerate missing payments ($\tau_R = 4$).

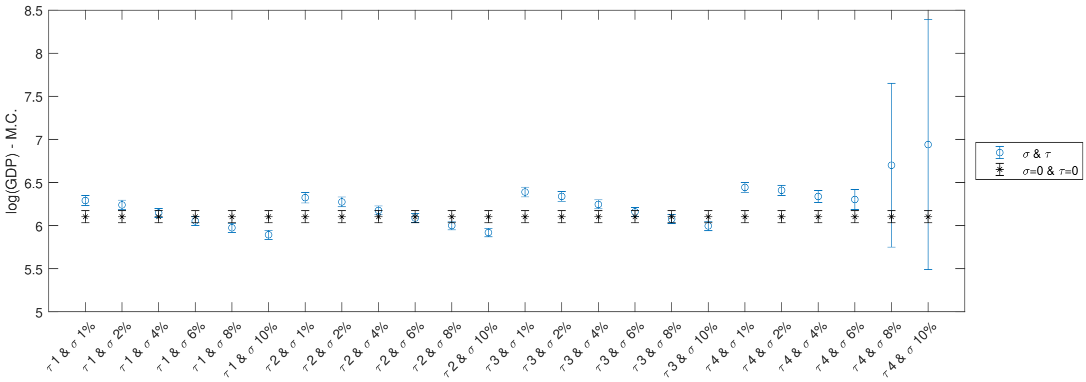

Figure 2: Long run mean of GDP obtained by averaging across 20 Monte Carlo simulations with $\eta = 1/4$ in the benchmark scenario (black stars) and the IR scenario (blue circles). Vertical segments represent one standard deviation from the mean.

In order to check the robustness of these results, we have run 20 Monte Carlo simulations for each of the 24 combinations of σ and τ_R with the same set of parameter values but different random seeds. In fig. 2 we plot the mean and the standard deviation of GDP generated by these MC simulations over the time window considered. Average GDP can be interpreted as a robust measure of the long run mean of GDP or quasi-steady state. The figure clearly confirms the pattern presented in facts 1 and 2. Average GDP in the IR scenario is bigger (smaller) than average GDP in the benchmark for low (high) values of σ. Moreover, the cut-off value of σ seems to increase with the bank's tolerance. A longer grace period enhances the positive (indirect) effect of R&D on output. With $\sigma > 0.06$ and $\tau_R = 4$ the average GDP in the IR scenario is much higher than in the benchmark but there is also very high volatility, possibly due to the tendency of the economy to take off along an increasing growth path. As expected, average GDP is monotonically increasing with the bank's tolerance.

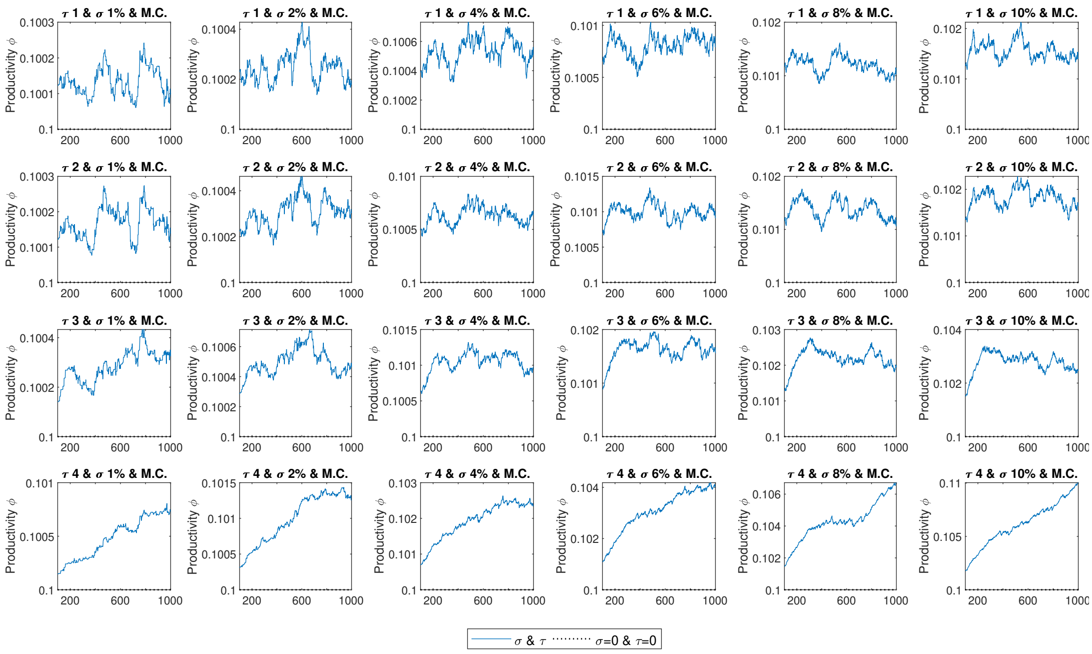

Figure 3: Time evolution of the average productivity of firms with $\eta = 1/4$ in the IR scenario.

In Fig. 3 we plot the dynamics of productivity (averaged across firms) for all the 24 combinations of σ and τ_R.

Fact 3 *Productivity is fluctuating around an almost stationary long run mean for all* τ_R *with the exception of* $\tau_R = 4$. *In the latter case productivity shows an upward trend. As expected, productivity is increasing with* σ *and* τ_R. [11]

[11] The benchmark scenario, characterized by $\sigma = 0$, is not shown. In the benchmark, in fact, by construction for each firm productivity would be constant and equal to the initial condition. In simulations the initial condition for productivity is $\phi_0 = 0.1$ uniform across firms.

Let us now focus on firms' financial fragility. In figure 4 we show the time evolution of the number of bankrupt firms[12] in the benchmark and the IR scenarios. Three striking stylized facts emerge from these simulations:

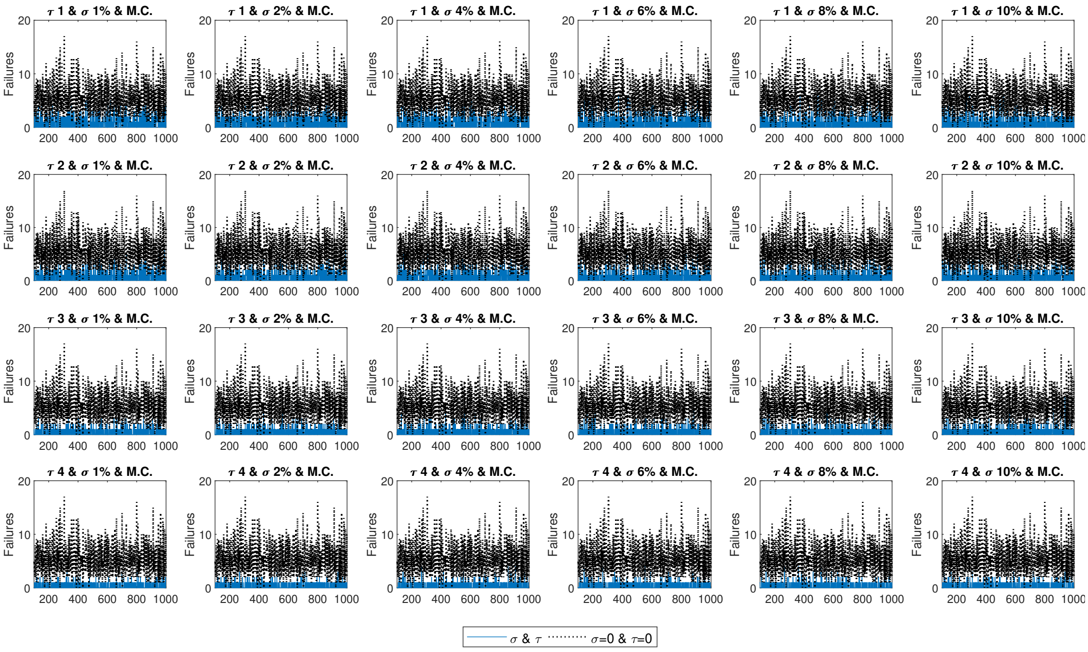

Figure 4: Time series of the number of bankrupt firms in the benchmark (black dashed line) and the IR scenario (blue solid line).

Fact 4 *Regardless of the numerical values of σ and τ, figure 4 shows that the number of bankrupt firms in the IR scenario is remarkably lower than in the benchmark.* In the IR case, in fact, the number of defaults obtained by averaging across 20 Monte Carlo simulations is 1.5 (st. dev. 0.94).

Fact 5 *The average number of defaults mentioned in fact 4 increases with σ but decreases with τ.* In fact for $\tau = 4$ the average number of defaults falls to 0.72 (st. dev 0.31).

Fact 6 *The time series of the number of bankruptcies in both the benchmark and IR scenarios are stationary. The fluctuations in GDP therefore are not due to waves of approximately similar bankrupt firm, but rather to the default*

[12]We consider all the bankruptcies, whatever the reason: excess of liabilities over asset or persistent liquidity shortages.

of few big firms.

We turn now to aggregate leverage measured by the ratio of total loans to the aggregate equity of firms. The average leverage of the system in the

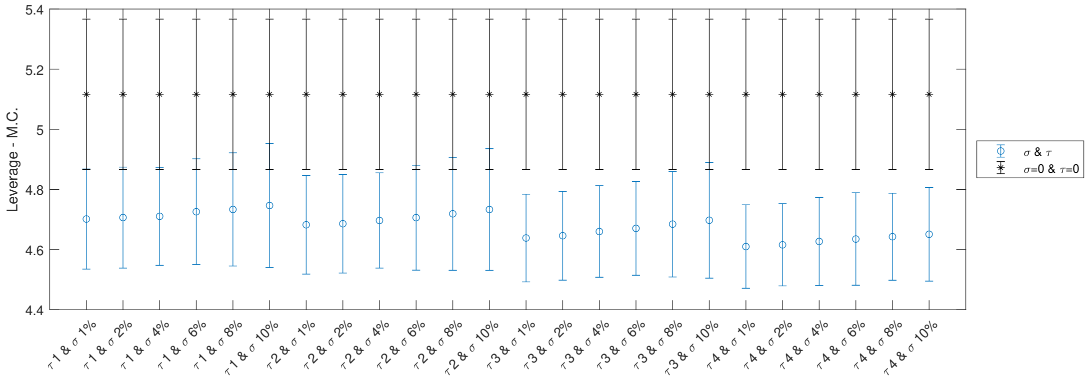

Figure 5: Aggregate leverage obtained by averaging across firms and across 20 Monte Carlo simulations with $\eta = 1/4$ in the benchmark scenario (black stars) and the IR scenario (blue circles). Vertical segments represent one standard deviation from the mean.

two scenarios is shown in Fig.5.

Fact 7 *From figure Fig.5 we infer that, regardless of the numerical value of σ and τ, the corporate sector is financially more robust in the IR scenario, i.e., in the presence of R&D investment and a forgiving bank.*

Fact 8 *The average leverage clearly increases with σ and shows a mild tendency to decrease with τ.*

Facts 4 and 7 are clearly related. Being the driver of innovation and the increase in productivity, R&D boosts output, profits and equity accumulation. This makes innovating firms financially more robust - i.e., characterized by a lower leverage - and less prone to bankruptcy.

Also facts 5 and 8 are related. Being an element of cost, a high propensity to invest in R&D may have a lower positive impact on output and equity accumulation, especially for firms whose R&D effort does not end up in innovation. When σ is high, firms become more financially fragile and are more likely to go bankrupt. Higher tolerance on the part of the bank allows to mitigate these negative effects on the firm's balance sheet and surviving probability.

9.2 (Almost) perfect competition

We now turn to the market form of (almost) perfect competition characterised by high price elasticity and almost zero market power ($\eta = 0.0001$). Figure 6 shows the dynamics of GDP in almost perfect competition in the

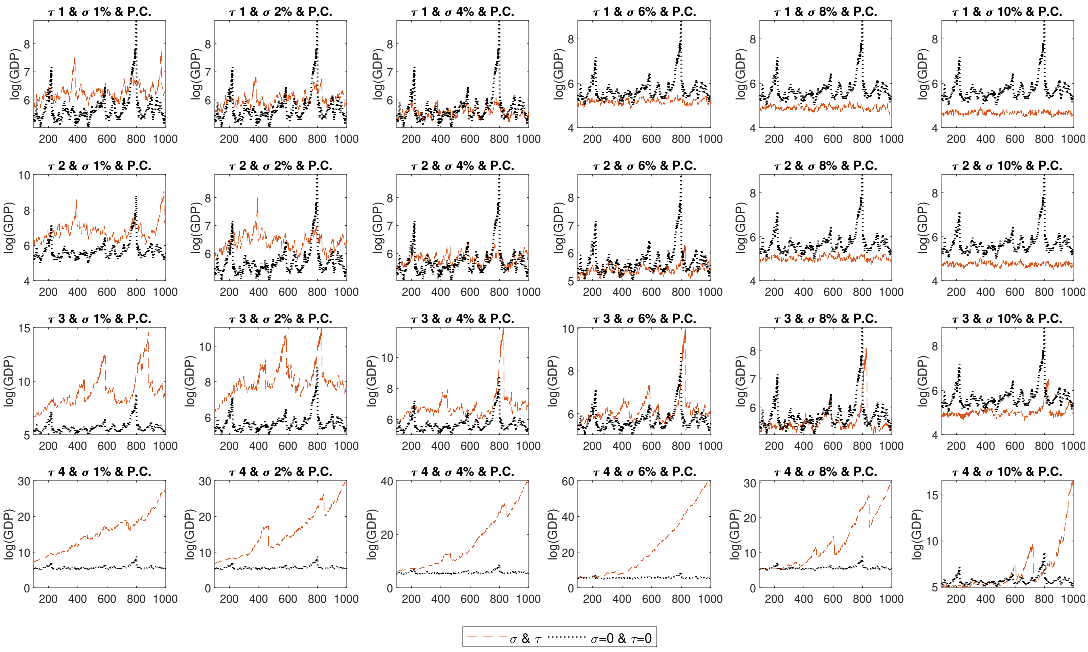

Figure 6: Time evolution of GDP generated by a single simulation in almost perfect competition ($\eta = 1/10000$) in the Benchmark (black dashed line) and the IR scenario (red dashed line). The black dashed line is the same in all the panels. The red dashed line changes depending on the parameterization.

Benchmark and in the IR scenario (black dashed line and red dashed line respectively). As with market power, in the benchmark, GDP fluctuates across a stationary long run mean. Also in the IR scenario GDP is generally stationary in the long run with the exception of the last row which clearly show an upward trend of GDP.

Contrary to the case of market power, however, investment in R&D has a negligible impact on GDP for low values of σ and τ_R.

Fact 9 *When η tends to zero, for $\tau_R \leq 3$ (i) when $\sigma \leq 0.06$ the time series of GDP in the IR scenario and in the Benchmark practically overlap, (ii) when $\sigma > 0.06$ GDP in the IR scenario lies below GDP in the Benchmark.* It takes at least $\tau_R = 3$ to make the impact of low levels of σ noticeably favourable at the aggregate level.

Fact 10 *With $\tau_R = 4$ the dynamics changes in nature: in the IR scenario the economy shows a clear exponential trend for any σ. Notice, however, that the growth rate of GDP exhibits an inverse U-shaped relationship with the propensity to invest in R&D, increasing up to $\sigma = 0.06$ and then decreasing.* Finally, by comparing Fig. 1 with Fig.6 another important difference between monopolistic and perfect competition emerges:

Fact 11 *Aggregate output, as expected, is on average higher in almost perfect competition than in monopolistic competition, but it is also considerably more volatile.* In fact, average aggregate output computed using all σ and all τ_R over 20 Monte Carlo simulations is 8.22 Iin logs; st. dev. 0.74) with almost perfect competition and 6.20 (st. dev. 0.38) with market power.

Although the gap between the average value of productivity computed for each σ and τ over 20 Monte Carlo simulations in the two market structures is low (0.1014 (st. dev. 0.0002) in monopolistic competition vs. 0.1 (st. dev. 0.0009) in perfect competition), we can appreciate an important difference by inspecting Fig. 7 which shows productivity as a function of σ and τ. In the presence of market power average productivity increases with σ and τ (see Fact 3). On the contrary:

Fact 12 *In the context of almost perfect competition average productivity exhibits, especially for high values of τ_R, an inverse U-Shaped relationship with σ.* Productivity is increasing (decreasing) for low (high) values of σ. In the end, therefore, some market power is necessary to invest in R&D, otherwise, as in the case of perfect competition, for very high σ the costs of innovation outweigh the benefits.

Let's now turn to bankruptcies and financial fragility. From Fig.8 – that shows the average number of bankruptcies in the benchmark and in the IR scenarios (black stars and red circles, respectively) obtained by running 20

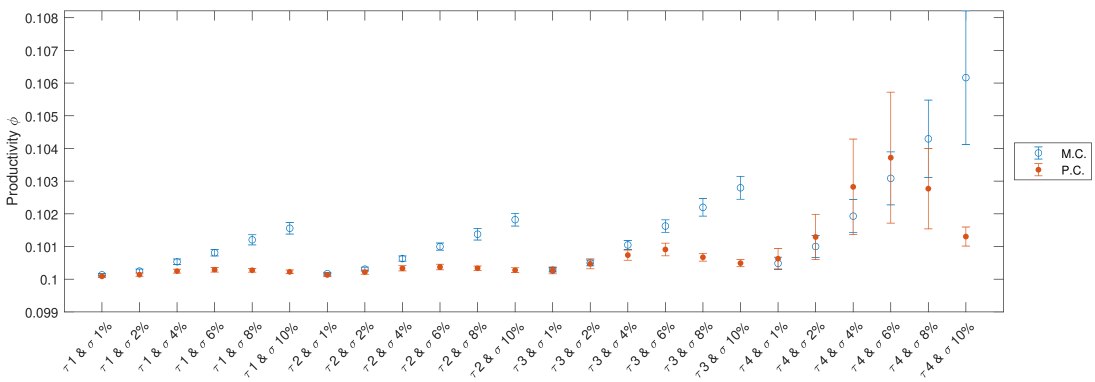

Figure 7: Average productivity in the presence of market power and in the (almost) perfect competition frameworks (empty blue circles and full red circles, respectively) in the IR scenario. Vertical segments represent one standard deviation from the mean. Averages with their standard deviations are obtained by running 20 Monte Carlo simulations.

Monte Carlo simulations – we infer the following fact:

Fact 13 *Under almost perfect competition, for high σ the benchmark and the IR scenarios produce the same number of bankruptcies.* This is a major difference with respect to the case of market power. In the latter setting, in fact, the number of exiting firms in the IR scenario is always remarkably lower than in the benchmark (see fact 4). As expected, also in this framework, increasing bank tolerance reduces the number of bankruptcies.

Overall, under almost perfect competition the macroeconomic landscape is more volatile and the risk of bankruptcy is higher than in the case of market power. In fact, in the former market structure, bankruptcies are much higher and increasing dramatically with σ. The grace period should be long enough (at least 3 sub-periods) and the cost incurred to carry on R&D sufficiently low to generate the same financial fragility as in the presence of market power.[13]

Last but not least, we explore the relationship between firms' productivity life expectancy in the two market structures. Fig.10 shows the scatter plots

[13]The outcome of simulations on the aggregate leverage under almost perfect competition are in line with that obtained in the case of market power (see Fig. 9) and are therefore omitted.

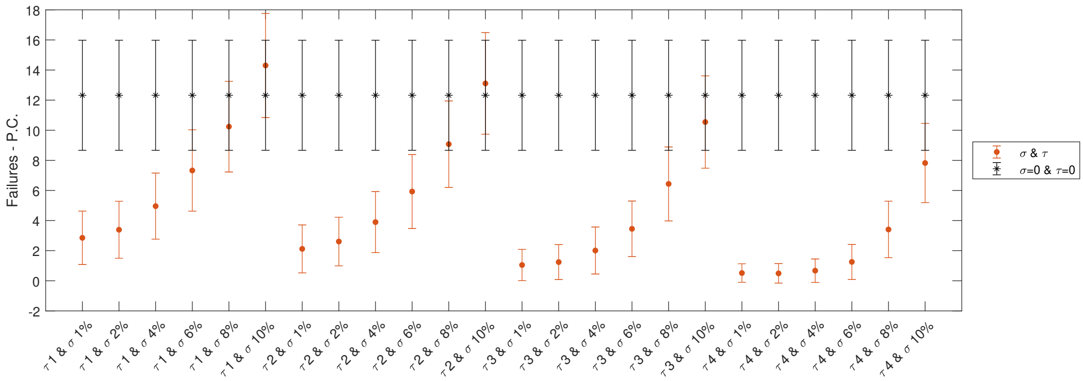

Figure 8: Average number of bankruptcy (with standard deviation) in the perfect competition framework in the benchmark (black stars) and in the IR (red circles) scenarios. Averages with their standard deviations are obtained by running 20 Monte Carlo simulations.

of the number of surviving firms and their productivity with market power and in almost perfect competition (blue circles and red circles, respectively).

Fact 14 *The higher the firm's productivity, the longer the firm's life. This is particularly evident in the presence of market power.*

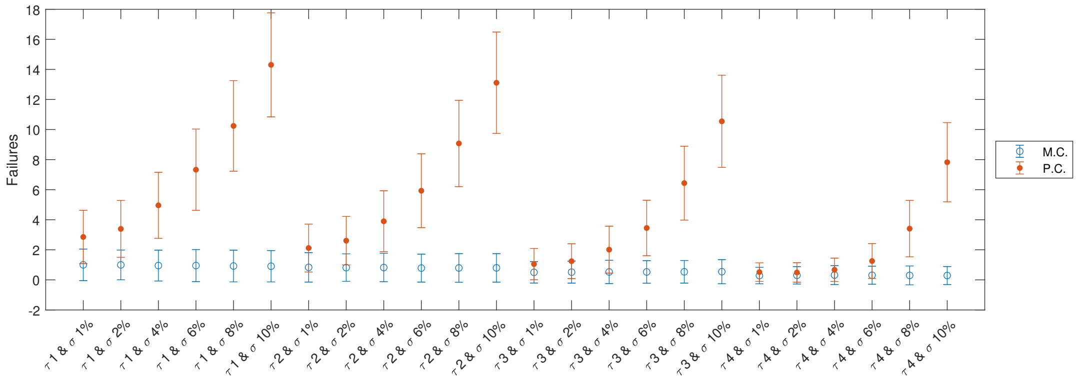

Figure 9: Average number of firms' bankruptcies (with standard deviation) in the monopolistic and (almost) perfect competition frameworks (empty blue circles and full red circles, respectively) in the IR scenario. Averages with their standard deviations are obtained by running 20 Monte Carlo simulations.

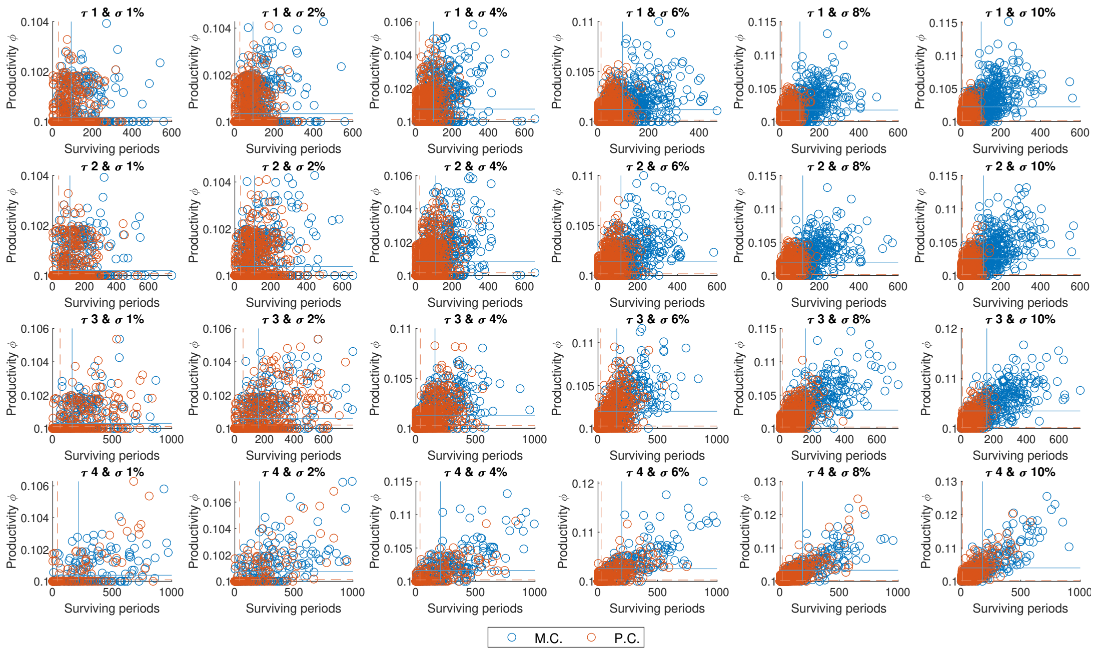

Figure 10: Scatter plot of the lifetime of firms and their productivity in the monopolistic and perfect competition frameworks (empty blue circles and full red circles, respectively) in the IR scenario.

10 Conclusions

In this paper we have explored the complex nexus of interrelations among market power, innovation and financial fragility by means of a macroeconomic agent based model whose core is the Dixit-Greenwald-Stiglitz theory of firm behaviour. In this setting the monopolistic competitive firm spends in R&D to innovate, boost productivity and increase its market share, being constrained by the availability of finance. In the presence of a financing gap the firm asks a loan and thereby becomes exposed to the risk of bankruptcy. To take the borrower's risk into account, the firm incur additional bankruptcy costs. The optimal firm's size is therefore increasing with net worth and productivity – the variables that define the firm's state – and decreasing with market power. The state of each firm evolves over time due to changes in productivity obtained by R&D expenditure and changes in net worth generated by the accumulation of profits. The model economy is populated by a sizable number of firms, one bank and households. The bank extends loans to firms (prioritizing the most innovative ones) and sets the interest rates depending on the firms' leverage.

Simulations show that in the presence of market power firms are more innovative and financially robust and less prone to bankruptcy. These features have not surfaced so far in standard characterization of monopolistic competition. Moreover, the dynamic pattern changes in nature when the bank is more willing to postpone the bankruptcy and exit of borrowing firms. In this case GDP takes off along a growth path for R&D expenditure sufficiently high.

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