# Market Power, Technical Progress and Financial Fragility

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**Abstract**

We explore the relations among market power, innovation and financial fragility by means of a macroeconomic agent based model whose core is the Dixit-Greenwald-Stiglitz (DGS) theory of firm behaviour, which enrich the Dixit-Stiglitz model of monopolistic competition with the Greenwald-Stiglitz notion of the risk-averse firm. In our DGS setting monopolistic competitive firms finance production by borrowing funds from banks and are exposed to the risk of bankruptcy, which entails additional bankruptcy costs. Moreover, they spend in R&D to boost productivity and increase their market share. 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. 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.

**Keywords**: Market power, Net worth, Productivity, Debt relief.
**JEL codes**

# 1 Introduction

In the canonical model of monopolistic competition developed by Dixit and Stiglitz, the firm is conceived as a static profit maximizer whose productivity and market share, in symmetric equilibrium, are constant and equal to those of its competitors. Moreover the firm does not face any financing constraint. In the real world of imperfect competition, firms (i) strive to increase their market share by spending in R&D to access product innovation and increase productivity; (ii) face financing constraint and strive to survive by validating debt commitments. These two features of the firms' activity interact in both directions. On one hand, a sufficient volume of finance is necessary to make R&D possible 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 the real world market power, technical progress and financial fragility are intertwined both at the firm level and in the macroeconomy.

In the literature, these three essential features of firm activity have been generally dealt with separately or in pairs. The relationship between market power and technical progress has been extensively studied, leading to two strands of literature based on the neoclassical approach typical of contemporary industrial organization and on the Schumpeterian approach, which has inspired the endogenous growth literature *à* la Aghion and Howitt and the evolutionary literature *à* la Nelson and Winter.

Also the relationship between technical progress and financial fragility has been analyzed in the evolutionary literature, albeit less extensively than the previous nexus of market power and innovation.

Finally, the relationship between market power and financial stability has been extensively studied but mainly with reference to the *credit market* and the *banking industry.* To the best of our knowledge the relationship between imperfect competition on the *goods market* and the financial fragility of the non-financial firms has been substantially neglected. In canonical macroeconomic models with financial frictions, in fact, financially constrained firms are generally operating in a perfect competition setting.

For instance, in the pioneering work of Bernanke, Gertler and Gilchrist, "entrepreneurs" produce a homogeneous wholesale good under perfect competition. These firms 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. Monopolistic competitive agents are undoubtedly part of the model, but they are retailers who buy homogeneous goods from entrepreneurs and differentiate them to produce varieties and earn a profit margin. Retailers are not financially constrained.
Greenwald and Stiglitz (1993)) consider a different setting in which perfectly competitive firms incur bankruptcy costs. Albeit the roots of the financial friction are different (lender's risk in the case of Bernanke and co-authors, borrower's risk in Greenwald and Stiglitz), in both cases the market structure is perfectly competitive.

In this paper we explore the interrelations among market power, technical progress and financial fragility by means of an agent based model of monopolistic competitive firms which differ from one another along two profiles: financial fragility, measured by net worth, and innovating capacity, measured by productivity. Our theory of firm behavior blends the simple Dixit-Stiglitz model of monopolistic competition with R&D expenditure along Nelson-Winter lines and bankruptcy costs *à* Greenwald-Stiglitz.
We start from a canonical Dixit-Stiglitz framework in which each firm faces a downward sloping iso-elastic demand curve and sets the individual price and quantity by equating the marginal revenue and the operating marginal cost. We depart from this benchmark first of all by introducing a random shock to demand that brings about uncertainty over the exact location on the price-quantity plane of the inverse 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. 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 use the DGS theory of firm behaviour to build an agent based model centered on firms along the lines of Delli Gatti et al. (2005) and Tedeschi et al. (2021). 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 plus 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. For simplicity we assume that there is only one bank. Total credit supply is limited by prudential capital requirements imposed on the bank by regulators. The bank charges firm-specific interest rates 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.

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. Therefore 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 banks stop lending, illiquid firms will not survive and will exit. In this case banks will experience a loss. If, on the other hand, banks agree to restructure debt and keep lending, firms survive and may be able to fulfill interest payments. We assume that banks are willing to reschedule debt. Rescheduling consists in granting additional time for the defaulting firm to reimburse debt. Notice that this also means that some firms characterized by low productivity will survive (zombie firms in contemporary jargon). It may well be the case that these firms will experience again a liquidity shortage in the future, in which case banks will record higher losses.[1]

In this context, there are two drivers of change, one for each variable determining the state of the firm. First, the firm engages in R&D to access innovation and increase productivity in order to increase both profitability and market share. Second, after interest payments, profits are used to accumulate net worth and strengthen the financial position of the firm. Hence the state of the firm changes over time.

In this model three parameters play a relevant role: the degree of market power measured by the inverse elasticity of demand $\eta$, the effort in R&D investment measured by the fraction of revenue spent in research $\sigma$ and the "patience" or forgiveness of the bank measured by the length of the grace period $\tau_R$ granted to defaulting firms. The behaviour of lenders is in fact key in determining the performance of the borrowing 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

[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).

in the benchmark for low $\sigma$ while it lies below the benchmark for high $\sigma$. 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 $\sigma$ and lies below GDP in the Benchmark for $\sigma$ 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 $\sigma$.
Second, regardless of the numerical values of $\sigma$ and $\tau$, 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 $\sigma$ 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.
Aggregate output, as expected, is on average higher in almost perfect competition than in monopolistic competition, but it is also considerably more volatile.

The paper is organized as follows. In Section 2 we describe the production function and the cost structure of the individual firm. In Section 3 we present the building blocks of the DGS theory of firm behaviour. Section 4 shows the determination of the firm's optimal size. In section 5 we discuss the way in which R&D translates into an increase of productivity. Section 6 describes the behaviour of the bank. In section 7 we present the sequence of events on the markets for goods and for credit and credit arrangements (in normal times and in the presence of illiquidity and default, debt rescheduling included). In section 8 we present and comment the results of the simulations. Section 9 concludes.

# 2 Technology and cost structure

Consider a population of $N_F$ firms. 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:

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

where the productivities of capital and labour $\phi_{i,t-1}$ and $\nu_{i,t-1}$ represent the state of technology 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 so that capital intensity does not change over time: $\dfrac{K_{i,t}}{N_{i,t}} = \dfrac{\nu_{i,t}}{\phi_{i,t}} = \dfrac{\nu_{i,t-1}}{\phi_{i,t-1}} = k_i$.
The productivity of capital is firm specific. Hence in every period $\phi_i$ has a certain probability distribution over a positive support. This distribution evolves over time due to technical progress. Since, by construction, $\nu_{i,t-1} = k_i\phi_{i,t-1}$, 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 $N_{i,t} = \frac{K_{i,t}}{k_i} = \frac{Y_{i,t}}{k_i\phi_{i,t-1}}$.

Let's denote with $w$ the real wage (uniform across firms) and with $gr_i$ the firm-specific user cost of capital. 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 $\gamma_{i,t} := \frac{w_t}{k_i} + gr_{i,t}$ is the (operating) cost per unit of capital and

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

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

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

# 3 Market power, 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 therefore 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, $\varepsilon$ is the absolute value of the price elasticity of demand and $u_{i,t}$ is a stochastic demand shock with expected value $E(u_{i,t}) = 1$ and finite variance. We assume $\varepsilon \in (1, \infty)$. The inverse demand function therefore is

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

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), (2) and (4) we can write expected operating profits as follows:

$$E(\pi_{i,t}) = Y_{i,t}^{1-\eta} - \frac{\gamma_{i,t}}{\phi_{i,t-1}} Y_{i,t} \tag{5}$$

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 by optimally choosing the size $Y_{i,t}$. Hence expected revenue is $E(p_{i,t})Y_{i,t} = Y_{i,t}^{1-\eta}$.

Let's assume that internal finance is in principle 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

$$A_{i,t-1} < c_{i,t} Y_{i,t} \tag{6}$$

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

$$A_{i,t} = A_{i,t-1} + \pi_{i,t}. \tag{7}$$

Because of the uncertainty surrounding profits (due to the random shock $u_i$), the firm may go bankrupt. Bankruptcy occurs at time t if net worth becomes negative $A_{i,t} < 0$, that is - recalling the definition of operating profits (3) - if

$$u_{i,t} < \frac{c_{i,t}Y_{i,t} - A_{i,t-1}}{Y_{i,t}^{1-\eta}} \equiv \overline{u}_{i,t}. \tag{8}$$

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 firm i is simply:

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

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

$$Pb_{i,t} = \frac{K_{i,t}^{\eta}}{2\phi_{i,t-1}^{1-\eta}}\left(\gamma_{i,t} - \frac{A_{i,t-1}}{K_{i,t}}\right) = \frac{Y_{i,t}^{\eta}}{2\phi_{i,t-1}}\left(\gamma_{i,t} - \phi_{i,t-1}\frac{A_{i,t-1}}{Y_{i,t}}\right) \tag{9}$$

The probability of bankruptcy is decreasing with productivity and with net worth and is increasing with size (measured by output or capital).[2]

# 4 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* $\Gamma_i$, 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: $C_{i,t}^{b} = bY_{i,t}^{2}$ with

[2]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.

$b$ a positive parameter uniform across firms. Hence the objective function is

$$\Gamma_{i,t} = E(\pi_{i,t}) - Pb_{i,t} b Y_{i,t}^2 \tag{10}$$

We depart from Greenwald and Stiglitz because we consider a monopolistic competition setting. In this setting, the profit maximization problem is subject to market demand. Plugging expected operating profit under monopolistic competition (5) and the probability of bankruptcy (9) in (10) we get

$$\Gamma_{i,t} = Y_{i,t}^{1-\eta} - \frac{\gamma_{i,t}}{\phi_{i,t-1}} Y_{i,t} - \frac{Y_{i,t}^{\eta}}{2\phi_{i,t-1}} \left( \gamma_{i,t} - \phi_{i,t-1} \frac{A_{i,t-1}}{Y_{i,t}} \right) b Y_{i,t}^2 \tag{11}$$

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 (11).

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

$$\Gamma_{Y_i} = \underbrace{(1-\eta)\, Y_{i,t}^{-\eta}}_{MR_{i,t}} - \underbrace{\frac{\gamma_{i,t}}{\phi_{i,t-1}}}_{MoC_{i,t}} - \underbrace{\frac{b}{2} \left[ \frac{\gamma_{i,t}}{\phi_{i,t-1}} (2+\eta)\, Y_{i,t}^{1+\eta} - A_{i,t-1} (1+\eta)\, Y_{i,t}^{\eta} \right]}_{MbC_{i,t}} \tag{12}$$

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 $\Gamma_{Y_i}$. 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 ($MoC_{i,t} = c_{i,t}$) and the Marginal bankruptcy Cost ($MbC_{i,t}$). In symbols:

$$(1-\eta)\, E(p_{i,t}) = MC_{i,t} = c_{i,t} + MbC_{i,t} \tag{13}$$

For the indebted firm, condition (6) guarantees that $MbC_{i,t}$ is positive and increasing with $Y_{i,t}$ while $MoC_{i,t}$ does not depend on output.

Since $\Gamma_{Y_i}$ 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 $\Gamma_i$) depending on the numerical values of the parameters and on the levels of the exogenous variables.

## 4.1 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 through an appropriate linearization in order to obtain a closed form solution which can easily be implemented in an agent based model.

First of all, 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

$$Y_{i,t}^{1-\eta} \approx \eta + (1-\eta) Y_i \tag{14}$$

Hence we can rewrite the condition for bankruptcy (25) as follows:

$$u_{i,t} < \frac{c_{i,t} Y_{i,t} - A_{i,t-1}}{\eta + (1-\eta) Y_{i,t}} \equiv \overline{u}_{i,t}. \tag{15}$$

To simplify computations, we ignore the intercept of the linearized revenue function in the denominator of (15) (with a minimal loss of generality for low values of the inverse elasticity). Using (2), the approximated probability of bankruptcy therefore is:

$$Pb_{i,t} = \frac{\overline{u}_{i,t}}{2} = \frac{1}{2(1-\eta)} \left( \frac{\gamma_{i,t}}{\phi_{i,t-1}} - \frac{A_{i,t-1}}{Y_{i,t}} \right) \tag{16}$$

In the linearized setting, thanks to (14), the expected operating profit is linear in output:

$$E(\pi_{i,t}) = \eta + \left[ (1-\eta) - \frac{\gamma_{i,t}}{\phi_{i,t-1}} \right] Y_{i,t} \tag{17}$$

Using (17) and (16) we get a quadratic objective function:

$$\Gamma_{i,t} = \eta + \left[(1-\eta) - \frac{\gamma_{i,t}}{\phi_{i,t-1}}\right] Y_{i,t} - \frac{1}{2(1-\eta)} \left(\frac{\gamma_{i,t}}{\phi_{i,t-1}} - \frac{A_{i,t-1}}{Y_{i,t}}\right) bY_{i,t}^2 \quad (18)$$

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

$$\Gamma_{Y_i} := \underbrace{1-\eta}_{MR_{i,t}} - \left[\underbrace{\frac{\gamma_{i,t}}{\phi_{i,t-1}}}_{MoC_{i,t}} + \underbrace{\frac{b}{2(1-\eta)}\left(\frac{\gamma_{i,t}}{\phi_{i,t-1}} 2Y_{i,t} - A_{i,t-1}\right)}_{MbC_{i,t}}\right] \quad (19)$$

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 $\Gamma_{Y_i}$ 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. In figure 1 we plot $\Gamma_{Y_i}$ for a specific set of numerical values of the parameters involved.

Thus, desired output is

$$Y_{i,t} = \frac{(1-\eta)^2\phi_{i,t-1} - (1-\eta)\gamma_{i,t}}{b\gamma_{i,t}} + \frac{\phi_{i,t-1}}{2\gamma_{i,t}} A_{i,t-1}. \quad (20)$$

and desired capital is

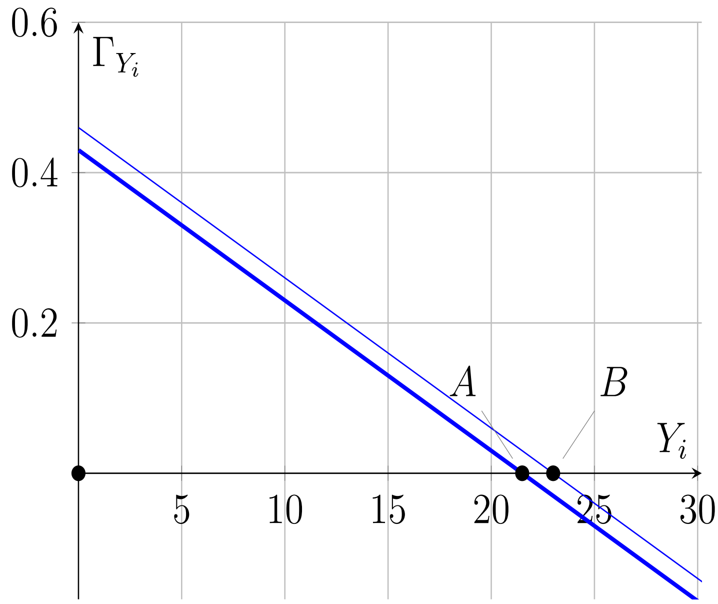
$$K_{i,t} = \frac{(1-\eta)^2\phi_{i,t-1} - (1-\eta)\gamma_{i,t}}{b\phi_{i,t-1}\gamma_{i,t}} + \frac{A_{i,t-1}}{2\gamma_{i,t}}. \quad (21)$$

Desired output is a linear increasing function of net worth and of productivity.[3]

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: $p_{i,t} = u_{i,t}E(p_{i,t}) = u_{i,t}$. On average, the relative price is equal to

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

Figure 1: $\Gamma_{Y_i}$ in the linearized setting

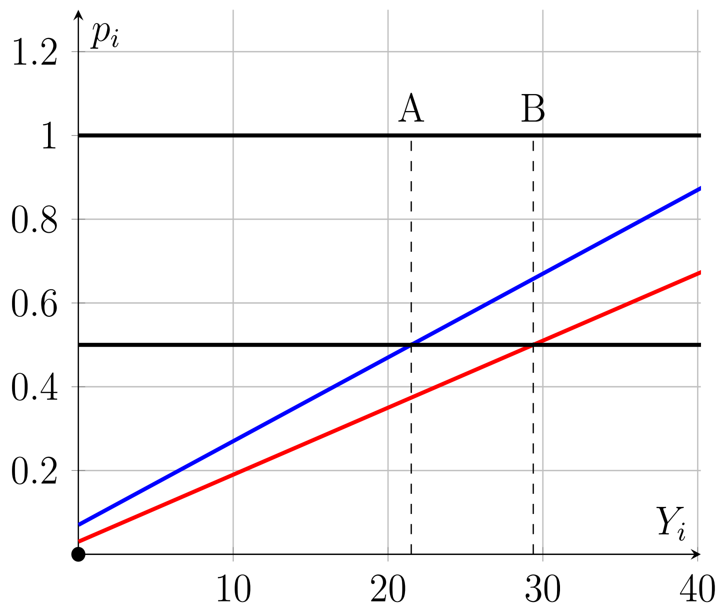



To plot the function we use the following parameter values: $\gamma_i = 0.5; \varepsilon = 2; b = 0.1; \phi_{i,0} = 5$. The blue thick line represents $\Gamma_{Y_i}$ when $A_{i,0} = 0.3$. The blue thin line represents $\Gamma_{Y_i}$ when $A_{i,1} = 0.6$. The optimal quantities are $Y_{i,0} = 21.5$ and $Y_{i,1} = 23$

one and the marginal cost, equal to marginal revenue, is equal to $1 - \eta$ and uniform across firms. Each firm generates the same marginal cost by means of different combinations of size, productivity and net worth. To illustrate this feature, in figure 2 we represent the marginal cost functions of firm i (red line) and firm j (blue line) that differ for productivity and net worth. The optimal size is determined at the intersection of the Marginal Cost line with the Marginal Revenue line. In the optimum therefore the marginal cost of all the firms must be the same. This condition can be obtained for different sizes. The j-th firm, in fact, has a combination of net worth and productivity such that its size is bigger than the i-th firm.

In a "macroeconomics from bottom up" perspective, aggregate output (GDP) is determined by summing production – determined as in (20) –

Figure 2: **Marginal cost, output and price**




Parameters: $\gamma_i = \gamma_j = 0.5; \varepsilon = 2; b = 0.1$. The blue thick line represents the marginal cost function of firm i with $A_{i,t-1} = 0.3$ and $\phi_{i,t-1} = 5$. The red thick line represents the marginal cost function of firm j with $A_{j,t-1} = 0.5$ and $\phi_{j,t-1} = 0.625$.

across firms:[4]

$$GDP_t = \sum_{i=1}^{N_F} Y_{i,t} \tag{22}$$

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

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

[4]GDP therefore can be written as follows $GDP_t = N_F Y_t$ where $Y_t := \frac{\sum_i Y_{i,t}}{N_F}$ is average output. From (20) follows, ignoring covariances among variables, that $Y_t \approx \frac{(1-\eta)^2\phi_{t-1}-(1-\eta)\gamma_t}{b\gamma_t} + \frac{\phi_{t-1}}{2\gamma_t}A_{t-1}$ where $\phi_{t-1}$ is average productivity, $\gamma_t$ agerage cost per unit of capital and $A_{t-1}$ is average net worth. In this approximated formulation, average (and therefore aggregate) GDP is increasing with average productivity and average net worth and decreasing with average cost per unit of capital. The relationship between aggregate output and GDP is non-monotonic. Output is decreasing with $\eta$, i.e., with market power – as expected – for low values of $\eta$ while it is increasing with market power for high values of $\eta$.

Individual investment is $I_{i,t} = K_{i,t} - K_{i,t-1}$ where $K_{i,t}$ is given by (21). 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 $Z_t = C_t + I_t$ (for the moment we abstract from Government expenditure). 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

Suppose now that firms invest in R&D in order to implement process innovation and increase productivity. Following the empirical literature, we assume that expenditure in R&D is financed by means of a fraction $\sigma$ of the firm's revenue. We must therefore slightly modify the setting of section 4 by introducing an additional expenditure, namely R&D, and an additional parameter, $\sigma$. Therefore the operating profit becomes:

$$\pi_{i,t} = u_{i,t} \left[\eta + (1-\eta) Y_{i,t}\right] (1-\sigma) - \frac{\gamma_{i,t}}{\phi_{i,t-1}} Y_{i,t} \tag{23}$$

Net worth evolves according to (7) and bankruptcy occurs if $A_{i,t} < 0$. Therefore we can determine a new cut-off value of the price shock:

$$u_{i,t} < \frac{c_{i,t} Y_{i,t} - A_{i,t-1}}{(1-\sigma)\left[\eta + (1-\eta) Y_{i,t}\right]} \equiv \overline{u}_{i,t} \tag{24}$$

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

$$Pb_{i,t} = \frac{1}{2(1-\sigma)(1-\eta)} \left( \frac{\gamma_{i,t}}{\phi_{i,t-1}} - \frac{A_{i,t-1}}{Y_{i,t}} \right) \tag{25}$$

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

$$\Gamma_{i,t} = \eta(1-\sigma) + \left[ (1-\eta)(1-\sigma) - \frac{\gamma_{i,t}}{\phi_{i,t-1}} \right] Y_{i,t} - \frac{1}{2(1-\eta)(1-\sigma)} \left( \frac{\gamma_{i,t}}{\phi_{i,t-1}} - \frac{A_{i,t-1}}{Y_{i,t}} \right) bY_{i,t}^2 \tag{26}$$

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

$$Y_{i,t} = (1-\sigma) \frac{(1-\eta)^2 \phi_{i,t-1} - (1-\eta)\gamma_{i,t}}{b\gamma_{i,t}} + \frac{\phi_{i,t-1}}{2\gamma_{i,t}} A_{i,t-1}. \tag{27}$$

$$K_{i,t} = (1-\sigma) \frac{(1-\eta)^2 \phi_{i,t-1} - (1-\eta)\gamma_{i,t}}{b\phi_{i,t-1}\gamma_{i,t}} + \frac{1}{2\gamma_{i,t}} A_{i,t-1}. \tag{28}$$

Let us now describe the dynamics of the firm's capital productivity, $\phi_{i,t}$ in relation with this type of 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, with parameter

$$Z_{i,t} = 1 - \exp(-\delta z_{i,t}), \tag{29}$$

where $z_{i,t} = \frac{R\&D_{i,t}}{K_{i,t}}$ and $\delta > 0$. As a consequence, the more a firm spends in $R\&D$, the higher the probability that it gains access to process innovation (see Dosi et al. 2010; Vitali et al. 2013 and Tedeschi et al 2014 for a similar approach). In this setting, if the Bernoulli process returns a positive probability of success, the law of motion of the firm's productivity is

$$\phi_{i,t} = (1 + \zeta_{i,t})\phi_{i,t-1}, \tag{30}$$

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

## 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 aggregate of all the loans the bank is willing to extend 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:

$$L_t^s = \frac{A_{t-1}^b}{\alpha}, \tag{31}$$

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 $1/\alpha = 12.5$

We assume that 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, however, is willing to borrow only the amount needed to reach the desired scale of activity.

We assume that the firm keeps a liquidity buffer proportional to capital: $M_{i,t} = mK_{i,t}$. 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: $L_{i,t} - L_{i,t-1} = (1 + m)I_{i,t} - \pi_{i,t}$.[5]

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

[5]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 (28). From (7) follows that $\pi_{i,t} = A_{i,t} - A_{i,t-1}$.

depends on the firm's leverage according to the following equation:

$$r_{i,t} = \beta \frac{L_{i,t}}{A_{i,t}}. \tag{32}$$

The bank's profit is the difference between the aggregate return on loans and the renumeration of depositors and the bank's shareholders:

$$\pi_{b,t} = \sum_i r_{i,t} L_{i,t} - \bar{r}_t (D_t + A_{b,t}), \tag{33}$$

where $\bar{r}$ is the average interest rate charged to borrowers. In words, depositors (and shareholders) are remunerated at a rate which is equal to the average interest rate charged to firms. Profits are accumulated to increase net worth. Hence the equity base of the bank obeys the following law of motion:

$$A_{b,t} = A_{b,t-1} + \pi_{b,t} - BD_t, \tag{34}$$

where $BD_t$ is "bad debt", i.e., the aggregate of bank losses due to the bankruptcy of borrowing firms.[6]

# 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 $\tau$ (for instance, if the period is a year and n=4, each subperiod is a quarter).

In each subperiod $\tau$:

- A fraction $\frac{1}{n}$ of annual output $Y_{i,t}$ (see equation (27) becomes available for sale: $Y_{i,\tau} = \frac{Y_{i,t}}{n}$.

[6] 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. We assume that household are willing to hold these deposits at the going interest rate on deposits.

- 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 $R_{i,\tau} = u_{i,\tau}\left[\eta + (1-\eta)Y_{i,\tau}\right]$.

- The firm spends a fraction of revenue for research and development: $R\&D_{i,\tau} = (1-\sigma)R_{i,\tau}$.

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

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

Thus, the sub-period *liquidity flow* is:

$$\lambda_{i,\tau} = (1-\sigma)R_{i,\tau} - W_{i,\tau} - \rho_{i,\tau}. \tag{35}$$

## 7.1 Credit arrangements

*At the end of period t*, if the firm's realized profit (the sum of sub-period flows of liquidity: $\pi_{i,t} = \sum_{\tau=1}^{n}\lambda_{i,\tau}$) is positive, the firm accumulates net worth according to (7): $A_{i,t} = A_{i,t-1} + \pi_{i,t}$.

If the firm has experienced a loss in the period ($\pi_{i,t} < 0$) but it is still technically solvent - i.e., if the loss is smaller than the equity inherited from the past $|\pi_{i,t}| < A_{i,t-1}$ - then it decumulates 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 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.

First of all, the bank ranks firms according to their willingness to innovate, measured by the level of R&D expenditure. A firm has a "low" (respectively: "high") willingness to innovate in the eyes of the bank 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*, i.e., the ratio of the size of the individual loss to the minimum of the 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 low propensity to invest in R&D, equity will be reduced by the amount of debt that was not validated with the liquidity obtained in good times. If the defaulting firm has a high propensity and its relative loss is small, then the firm will accept a reduction of net worth.

If the defaulting firm has a high propensity 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 $\tau_R$ (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 $\tau_R$, the more "patient" or forgiving the bank is.

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

# 8 Simulation results

We consider an economy populated by households, firms and a bank. The focus is on the corporate sector, which consists of $N_F = 100$ firms. For simplicity, given the focus of this paper, there is only one bank. Households spend all their wage earnings in consumption goods and supply all the labour the firms need (labour supply is abundant). 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 $\tau$.

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 10 parameters (uniform across firms). We set and keep fixed the following 7 parameters: $g = 1.1$, $w = 0.005$, $b = 1$, $\alpha = 0.08$, $\beta = 0.02$, $\delta = 2$, $k = 1$.[7]

We explore the parameter space consisting of the remaining 3 parameters ($\eta$, $\sigma$ and $\tau_R$) on a grid of two numerical values for $\eta$, six numerical values for $\sigma$ and four numerical values for $\tau_R$.

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

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

this scenario we run simulations for $\sigma = 0.01, 0.02, 0.04, 0.06, 0.08, 0.1$ and for $\tau_R = 1, 2, 3, 4$.

## 8.1 Market power

Let us first study the impact of market power on aggregate variables. In Figure 3 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 $\sigma$ and $\tau_R$, thereby generating 24 panels.

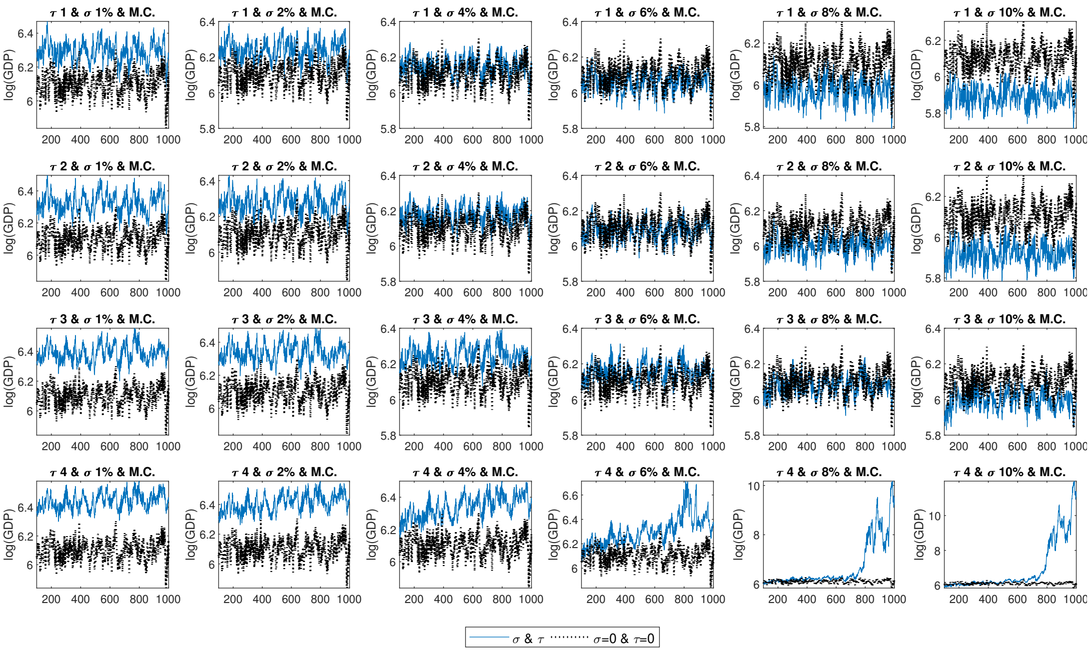



Figure 3: Time evolution of GDP generated by a single simulation in the presence of market power ($\eta = 1/4$) in (i) the Benchmark scenario (no R&D and no rescheduling) (black dashed line) and in (ii) the IR scenario with R&D expenditure (for $\sigma = 0.01, 0.02, 0.04, 0.06, 0.08, 0.1$) and debt rescheduling (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 $\tau_R$ ($\sigma$).

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.

**Fact 1** *For* $\tau_R < 4$*, the time series of GDP in the IR scenario in figure 3: (a) lies above that of GDP in the benchmark for* $\sigma \leq 0.02$*; (b) overlaps with the benchmark for* $0.02 < \sigma \leq 0.06$ *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 $\sigma$ the latter (former) effect prevails so that GDP is higher (lower) than in the benchmark. The cut-off value of $\sigma$ – 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* $\sigma$ *and takes off along a growth path for* $\sigma > 0.06$ *(blue solid line in the fourth row of fig.3).*

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 ($\tau_R = 4$).

In order to check the robustness of these results, we have run 20 Monte Carlo simulations for each of the 24 combinations of $\sigma$ and $\tau_R$ with the same set of parameter values but different random seeds. In fig. 4 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

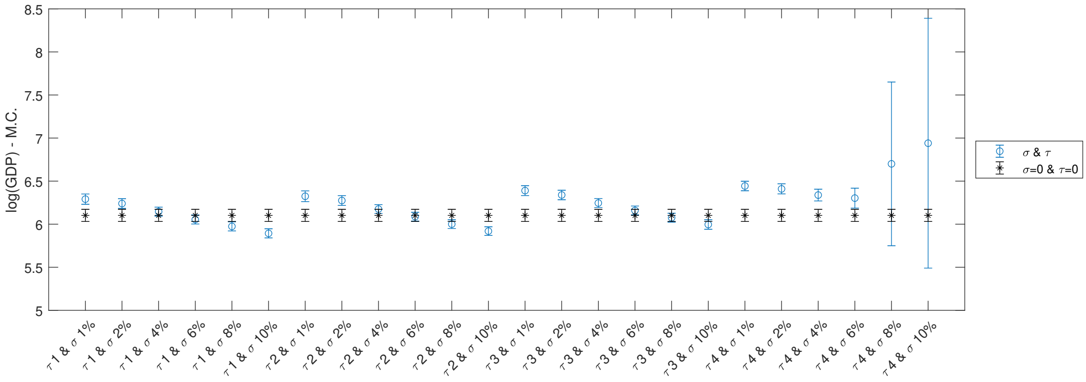


Figure 4: Long run mean of GDP obtained by averaging across 20 Monte Carlo simulations with $\eta = 1/4$ in the benchmark scenario (black stars) and the IR scenario (blue circles). Vertical segments represent one standard deviation from the mean.

IR scenario is bigger (smaller) than average GDP in the benchmark for low (high) values of $\sigma$. Moreover, the cut-off value of $\sigma$ 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.

In Fig. 5 we plot the dynamics of productivity (averaged across firms) for all the 24 combinations of $\sigma$ and $\tau_R$.

**Fact 3** *Productivity is fluctuating around an almost stationary long run mean for all* $\tau_R$ *with the exception of* $\tau_R = 4$. *In the latter case productivity shows an upward trend. As expected, productivity is increasing with* $\sigma$ *and* $\tau_R$. [8]

Let us now focus on firms' financial fragility. In figure 6 we show the time evolution of the number of bankrupt firms[9] in the benchmark and the IR

[8]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.

[9]We consider all the bankruptcies, whatever the reason: excess of liabilities over asset

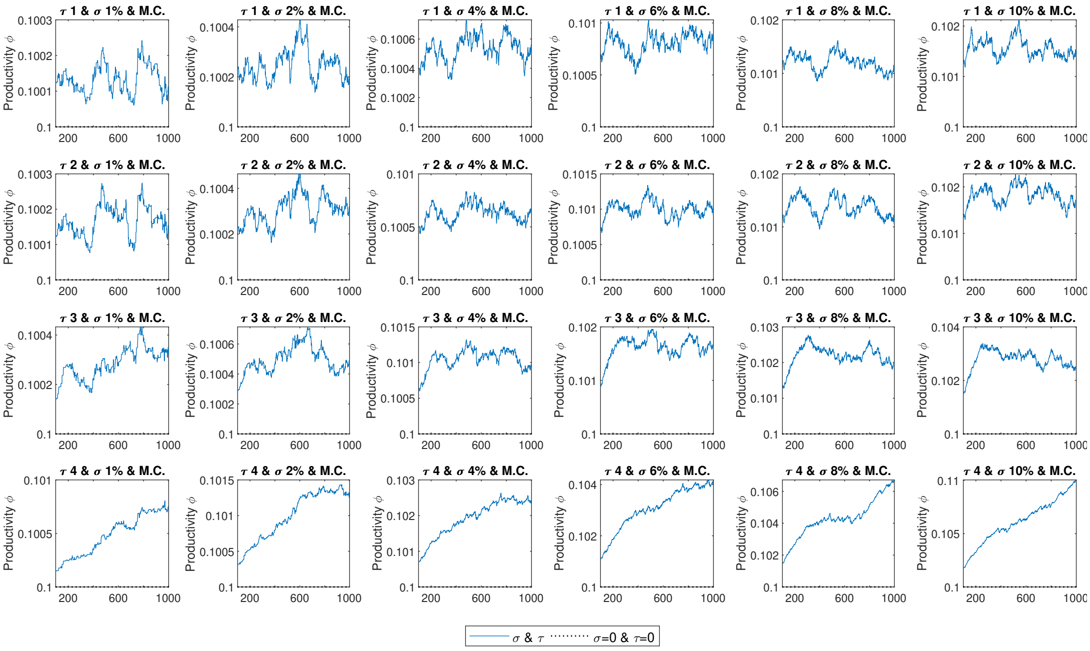



Figure 5: Time evolution of the average productivity of firms with $\eta = 1/4$ in the IR scenario.

scenarios. Three striking stylized facts emerge from these simulations:

**Fact 4** *Regardless of the numerical values of $\sigma$ and $\tau$, figure 6 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** *Interestingly the average number of defaults mentioned in fact 4 increases with $\sigma$ but decreases with $\tau$.* 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 of few big firms.*

We turn now to aggregate leverage measured by the ratio of total loans

or persistent liquidity shortages.

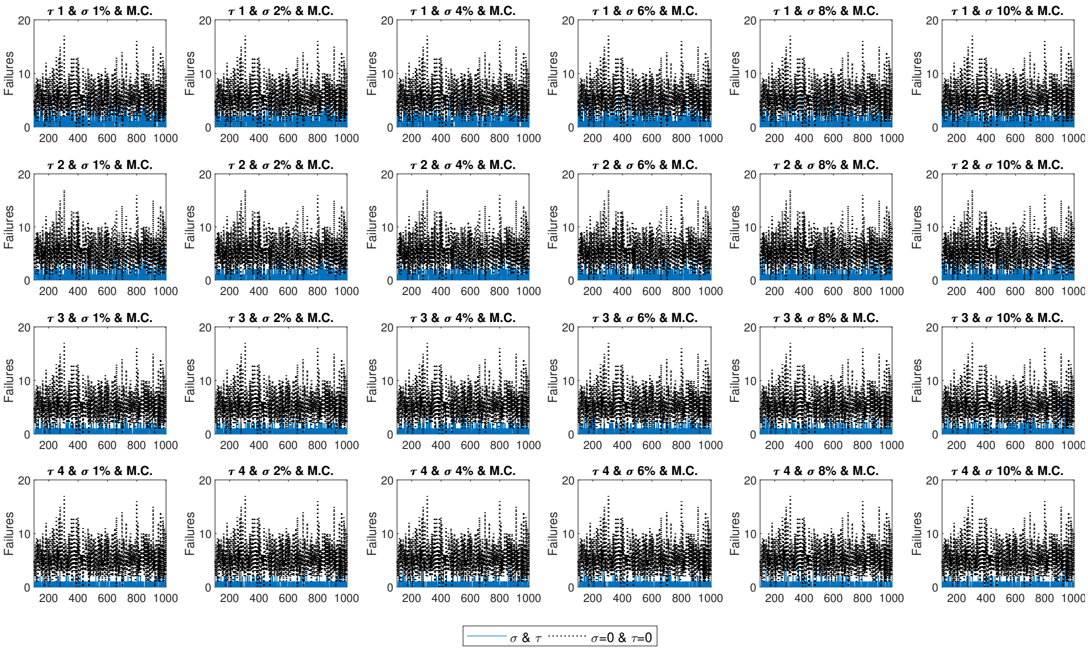


Figure 6: Time series of the number of bankrupt firms in the benchmark (black dashed line) and the IR scenario (blue solid line).

to the aggregate equity of firms. The average leverage of the system in the two scenarios is shown in Fig.7.

**Fact 7** *From figure Fig.7 we infer that, regardless of the numerical value of* $\sigma$ *and* $\tau$*, 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* $\sigma$ *and shows a mild tendency to decrease with* $\tau$*.*

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 $\sigma$ is high, firms become more financially fragile and are

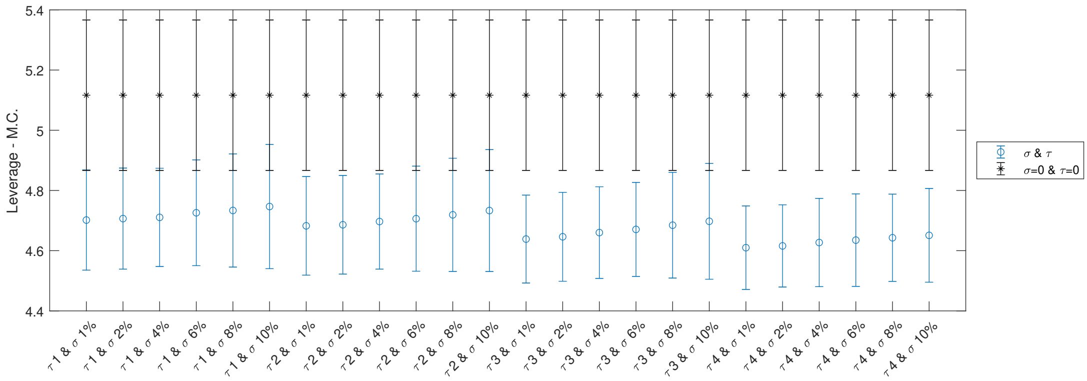



Figure 7: Aggregate leverage obtained by averaging across firms and across 20 Monte Carlo simulations with $\eta = 1/4$ in the benchmark scenario (black stars) and the IR scenario (blue circles). Vertical segments represent one standard deviation from the mean.

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.

## 8.2 (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 8 shows the dynamics of GDP in almost perfect competition in the 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 $\sigma$ and $\tau_R$.

**Fact 9** *When $\eta$ 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 $\sigma$ noticeably favourable

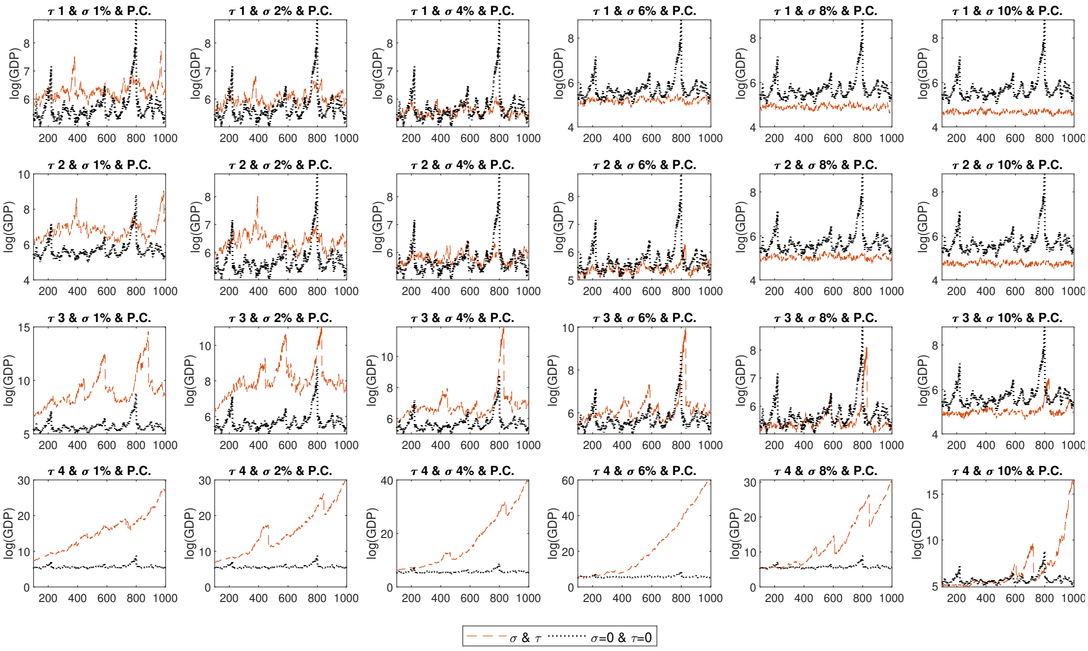



Figure 8: Time evolution of GDP generated by a single simulation in almost perfect competition ($\eta = 1/10000$) in the Benchmark (black dashed line) and the IR scenario (red dashed line). The black dashed line is the same in all the panels. The red dashed line changes depending on the parameterization.

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 $\sigma$. 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. 3 with Fig.8 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 $\sigma$ and all $\tau_R$ 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 $\sigma$ and $\tau$ 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. 9 which shows productivity as a function of $\sigma$ and $\tau$. In

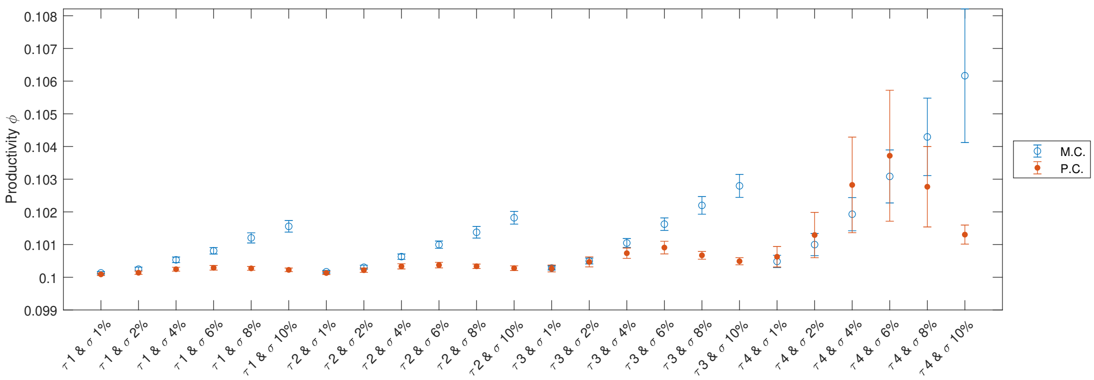


Figure 9: Average productivity in the presence of market power and in the (almost) perfect competition frameworks (empty blue circles and full red circles, respectively) in the IR scenario. Vertical segments represent one standard deviation from the mean. Averages with their standard deviations are obtained by running 20 Monte Carlo simulations.

the presence of market power average productivity increases with $\sigma$ and $\tau$ (see Fact 3). On the contrary:

**Fact 12** *In the context of almost perfect competition average productivity exhibits, especially for high values of $\tau_R$, an inverse U-Shaped relationship with $\sigma$.* Productivity is increasing (decreasing) for low (high) values of $\sigma$. 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 $\sigma$ the costs of innovation outweigh the benefits.

Let's now turn to bankruptcies and financial fragility. From Fig.10 – 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 Monte Carlo simulations – we infer the following fact:

**Fact 13** *Under almost perfect competition, for high $\sigma$ 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,

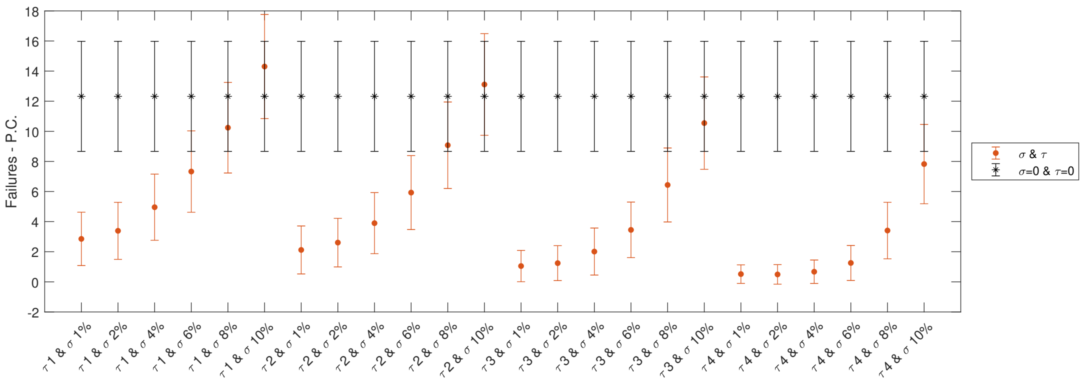


Figure 10: Average number of bankruptcy (with standard deviation) in the perfect competition framework in the benchmark (black stars) and in the IR (red circles) scenarios. Averages with their standard deviations are obtained by running 20 Monte Carlo simulations.

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 $\sigma$. 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.[10]

Last but not least, we explore the relationship between firms' productivity life expectancy in the two market structures. Fig.12 shows the scatter plots 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.*

[10]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. 11) and are therefore omitted.

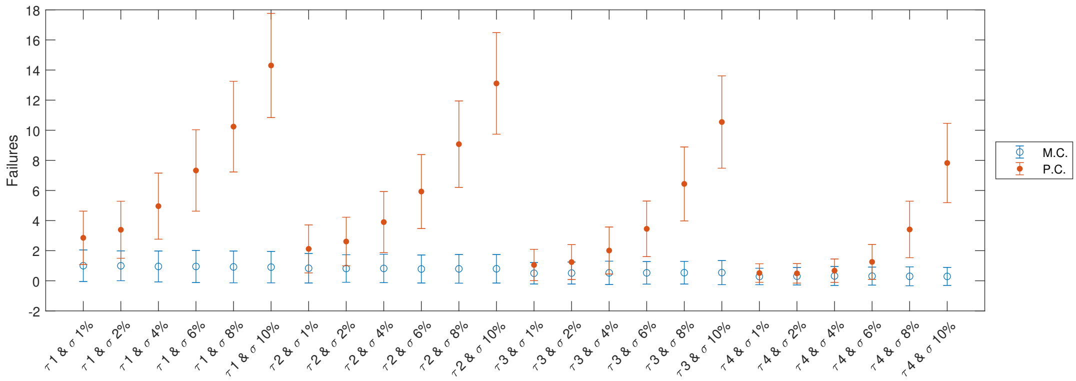



Figure 11: Average number of firms' bankruptcies (with standard deviation) in the monopolistic and (almost) perfect competition frameworks (empty blue circles and full red circles, respectively) in the IR scenario. Averages with their standard deviations are obtained by running 20 Monte Carlo simulations.

# 9 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 (not explicitly modelled). The bank extends loans to firms (prioritizing the most innovative ones) and sets the interest rates depending on the firms' leverage.

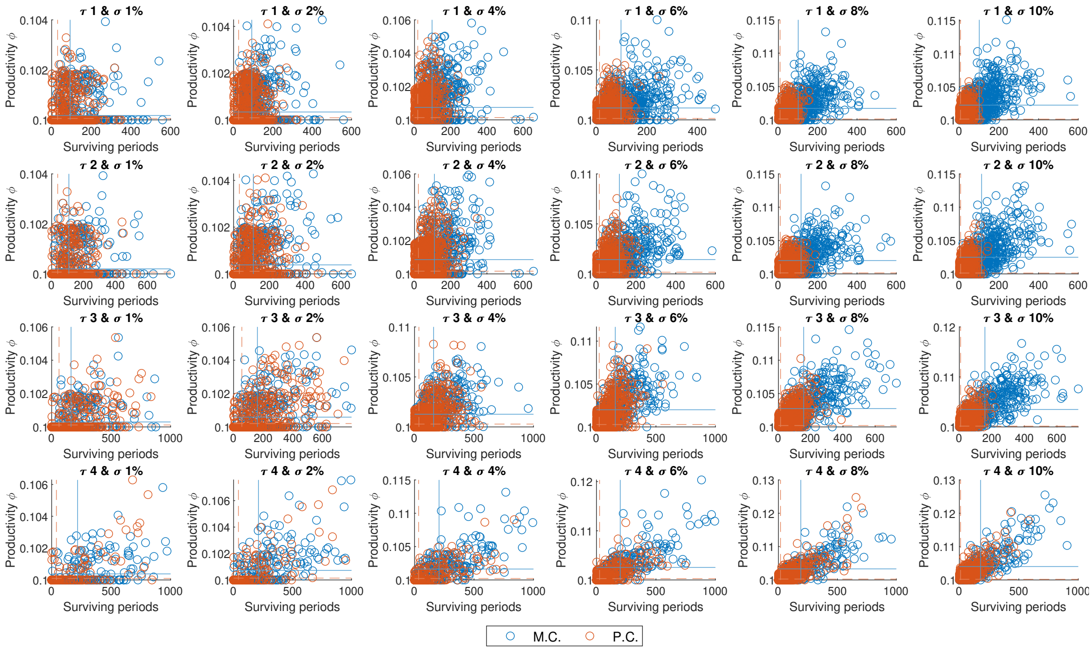


Figure 12: Scatter plot of the lifetime of firms and their productivity in the monopolistic and perfect competition frameworks (empty blue circles and full red circles, respectively) in the IR scenario.

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.

# References


Delli Gatti, D., Guilmi, C., Gaffeo, E., Giulioni, G., Gallegati, M., and Palestrini, A. (2005). A new approach to business fluctuations: heterogeneous interacting agents, scaling laws and financial fragility. *Journal of Economic Behavior and Organization*, 56(4):489–512.

Gilson, S. C., John, K., and Lang, L. H. (1990). Troubled debt restructurings: An empirical study of private reorganization of firms in default. *Journal of financial economics*, 27(2):315–353.

Greenwald, B. and Stiglitz, J. (1993). Financial market imperfections and business cycles. *The Quarterly Journal of Economics*, pages 77–114.

Moretto, M. and Tamborini, R. (2007). Firm value, illiquidity risk and liquidity insurance. *Journal of Banking & Finance*, 31(1):103–120.

Mosebach, M. (1999). Market response to banks granting lines of credit. *Journal of Banking & Finance*, 23(11):1707–1723.

Ongenah, S. and Smith, D. C. (2000). Bank relationships: A review9. *Performance of Financial Institutions: Efficiency, Innovation, Regulation*, page 221.

Tedeschi, G., Vidal-Tomas, D., Gallegati, M., and Delli Gatti, D. (2021). The macroeconomic effects of default and debt restructuring: an agent based exploration. *International Review of Economics & Finance*, 76:1146 – 1163.