# Growth, Business Cycle, Technological Change and Financing

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## Abstract

The literature has produced an extensive set of theories that explain why innovation and finance are important elements for understanding growth and business cycles. Despite the large body of knowledge on the subject, most studies have analysed the relation between growth and innovation, between growth and finance and between these two and business cycles separately. There is no theory or model that integrates growth, business cycles, innovation and finance under a unified framework. For this reason, the present article seeks to contribute to the goal of building such a unified theory by analysing some of the links that exist between growth, business cycle, innovation and finance. In order to do that, we have built and simulated an agent-based computational model featuring a large number of firms which interact with each other and with a banking system. Firms and banks' behaviour are modelled based on evolutionary micro-foundations. The result of the analysis of our simulations indicates that business cycles are unintended events derived from the interaction among firms and between firms and the banking system. In our model, financial and economic instability are emergent phenomena of modern capitalist economies. Moreover, we observe that a more risk tolerant financial sector might be better for long-run growth and short run economic and financial stability.

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## 1. Introduction

Economic theory has produced, through empirical and theoretical methods, a comprehensive body of knowledge about the links between growth and innovation and between growth and finance. Despite many interesting results, most part of the literature has studied the relationships of growth and innovation and of growth and finance separately. It's been only in recent years that some authors have begun to adopt an integrated approach to, empirical and theoretically explore the links between growth, innovation and finance simultaneously (Berentsen et al., 2012; Norden et al., 2014; Hsu et al., 2014; Kung and Schmid, 2015; Laeven et al., 2015).

Notwithstanding these recent contributions, no satisfactory microfounded framework has been developed capable of showing how innovation and finance activities can at the same time generate long-run growth and short-run business cycles.

The current article seeks to advance in the direction of building an integrated theory of growth and business cycle, where both phenomena are emergent properties of the firms' decision regarding innovation and financial strategies. We developed a micro-macro agent-based model (ABM) that demonstrates how Schumpeterian or technological competition has the potential to produce not only long-term growth but also business cycles when in the presence of a financial sector. Our ABM model sheds some light on the interactions and complex processes behind the emergence of the macroeconomic patterns of growth and business cycles. Competition among firms based on innovation, pricing strategies and temporary negative cash-flow financing are key elements that might explain the emergence of such phenomena.

The ABM approach can be employed to provide microfoundations to macroeconomic dynamics on the basis of computational agent-based adaptive descriptions of individual behaviour (Gaffeo et al., 2008). Rather than imposing macrodynamic rules, in our model growth and business cycles emerge from the interactions among firms and of those with the banking sector. There is nothing in the behaviour of firms nor in the system itself that deterministically produces cycles or financial crisis. These phenomena are emergent properties of the agents' interactions. One of the results of such interaction is the correlation between instability and innovation. The more innovative the economy, the more unstable it appears to be.

While there is a consensus that long-run growth depend on technological progress derived from innovation [1], there is no consensus on the sources of short-run business cycles. One explanation is that short-run business cycles depend on the cumulative performance of the firms and on the behaviour of the financial sector. If the later reacts pro-cyclically, then cycles are deeper, as described by Minsky (1982).

A crisis may begin when some firms fall behind in the technological race and need to finance their negative profits, accumulating debt. If these firms do not succeed in innovating during the next periods to restore their cash-flow, the financial sector risk-debt assessment increases which may increase in the economy's interest rate. Higher interest rate might cause some firms to go bankrupt. Such a financial crisis can reduce consumption not only through the labour market, as unemployment increases due to firms' bankruptcies, but also through the credit market, as higher interest rates reduce the individuals' capacity to consume durable goods.

As we can see, the financial sector has a dubious role in the economy: on the one hand, it contributes to growth as it provides finance to firms, which helps them to balance their negative profits and continue with their activities, including R&D. However, on the other hand, if a significant number of firms fall behind in the technological race and accumulate too much debt, the financial sector might respond by increasing interest rates which may turn the financial crisis into a generalized economic crisis.

The present paper contributes to the theoretical literature of economic growth, business cycles and macroeconomic dynamics by showing that it is possible to explain both, long-run growth and short-run business cycles, based on the links between innovation and finance. Our ABM model shows that the business cycle is neither an exclusive attribute of the agent's behaviour, nor a restriction or pre-existing property of the economy itself, but an emergent property of the interactive nature of the economic system.

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[1] A well-known result in the literature of endogenous growth.

## 2. The Growth-Innovation-Finance Puzzle

### 2.1. Growth and Finance

A vast literature has suggested the existence of a strong correlation between finance and growth. While there is much consensus on the link between finance and growth, establishing a causality direction still a controversial issue. Early studies on financial development and economic growth such as Goldsmith (1969), McKinnon (1973) and Shaw (1973), claim the existence of a strong link between the financial structure of a country and its physical infrastructure. According to Goldsmith (1969, p. 400) it "accelerates the economic growth and enrich the economic performance on an extension that facilitates the movements of funds for its best application, that is, to places on the economy where the funds will produce higher social return rates".

Data for the period of 1860-1963 presented by Goldsmith shows a secular increasing tendency on the proportion of the financial assets in comparison to the national gross product, for both developed and less developed countries. Despite the clear correlation, the author observes that it is difficult "to trust on the causal direction mechanism, that is, to decide if the financial factors were responsible for the economic development activity or if the financial development reflects the economic growth, whose impulse must be searched somewhere else". On another study, Cameron (1967) underlines the importance of financial factors on the economic development of many European countries. Guiso et al. (2004) provides empirical evidence of a positive association of financial development with productivity growth for the Italian economy.

Regarding the issue of causality, using Granger causality tests Hassan et al. (2011) find positive econometric evidence of a two-way causality between finance and growth in all regions but Sub-Saharan and East Asia & Pacific in the short run. In contrast, Levine (2005) finds that financial innovation plays a dominant role in shaping the rate of technological innovation and growth by accelerating the speed with which economic converge to the growth path of the economic leader occur. Even though the issue of the causality direction between growth and finance still be open to debate and analysis, some authors even question its existence (Working Paper, 2003; Chuah and Thai, 2004; Al-Awad and Harb, 2005). Shen et al. (2011) and Beck et al. (2012) find a non-linear relationship, positive at the beginning of finance development, and negative after some threshold size is reached. In all the studies analysed, the conclusion is normally conditioned to the sample of countries and on their income level. Even after many years, the relationship between economic growth and financial development is still an important and controversial issue among academics and policy-makers.

Economic theory has developed several explanations for the positive relationship between finance and growth. In general, the literature claims that by changing the incentives and restrictions, with which the economics agents come across, financial development improves risk management and thus contributes to reducing the effects of asymmetric information and transaction costs (Merton, 1995; Merton and Bodie, 1995). The development of financial intermediaries can stimulates economic growth as it enables the acquisition of more accurate information which improves risk assessment, contributes to risk sharing and improves asset allocation (Greenwood and Jovanovic, 1990).

According to the literature, the financial system exerts a positive effect on economic growth and development as a more developed financial system is more capable of correctly assessing the credit risk and of directing investment towards the most profitable opportunities. However, the financial sector may also be responsible for negative economic events such as financial and economic crises. Brown et al. (2009) observes that when companies need to finance their innovation projects they sometimes turn to the financial sector, a temporary or permanent shortage of credit to these kind of projects may result in significant short and long-run macroeconomic negative consequences. Therefore, while an increase in the supply and availability of credit might foster R&D expansion and growth, a credit contraction can cause an economic slowdown[2].

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[2]Brown et al. (2009, p. 153) observes that "...the U.S. has recently experienced a finance-driven cycle in R&D. From 1994 to 2004, there was a dramatic boom, and subsequent decline, in R&D: the ratio of privately financed industrial R&D to GDP rose from 1.40% in 1994 to an all-time high of 1.89% in 2000 before declining to an average of 1.70% from 2002 to 2004, according to a survey from the National Science Foundation. (...) From 1994 to 2004, there was also a dramatic boom and bust in both cash flow and external equity finance in these industries. Internal finance (cash flow) for publicly traded firms increased from $89 billion in 1993 to $231 billion in 2000, and then collapsed in 2001 and 2002. External public equity finance rose from $24 billion in 1998 to $86 billion in 2000, but then plummeted 62% in 2001.".

The ABM model developed on section 3 is built based on the assumption that, by modelling how the financial sector finances the firms' negative profits (cash-flow) rather than only their R&D expenses, the model is able to capture a broader picture of the channels through which growth, innovation and finance might be connected.

### 2.2. Finance and Innovation

The literature on growth, finance and innovation is vast and diversified. Some authors have focused their analysis specifically on the relation between finance and the innovation process and on how the financing of innovation might increase the growth rate (Arrow, 1962a). De la Fuente and Marin (1996) for instance, have shown that financial intermediaries contribute to growth by collecting information which, by improving their ability to provide risk-pooling services, facilitates the flow of resources to risky innovative activities, and ii) real sector growth feeds back into finance through changes in factor prices which increase the return to information-gathering by intermediaries.

An important set of authors agrees that the improvement of the financial mediation leads to better asset and resource allocation which mitigates the problem of adverse selection in the credit market (Bencivenga and Smith, 1991; Levine, 1991; Boyd and Smith, 1992; Saint-Paul, 1992). Moreover, better financial intermediaries improve monitoring activities and facilitate risk sharing. As a result, more productive R&D projects are funded increasing the economy's technological progress and growth rates. Morales (2003), shows that financial activity is growth promoting when research is financed by intermediaries. This result derives from the fact that financial intermediaries are able to reduce the incidence of researcher's moral hazard an thus increase research productivity.

King and Levine (1993) provide an slightly different explanation for the correlation between financing and innovation. The authors have developed an endogenous growth model, on which financial institutions grade potential entrepreneurs based on their chances of success in terms of productivity improvement. In this context, banks would diversify the risks associated with the projects by selecting and financing the ones with the highest expected profit, instead of the ones with the lower value.

Some authors might be even more emphatic on the importance of financial mediation. According to Galetovic (1996), when increased specialization is a necessary condition for growth. The author suggests that intermediaries are a necessary condition for growth to start and to persist, therefore sustained growth may not start if financial intermediaries do not emerge.

### 2.3. Agent-Based Models of Growth and Finance

The use of ABM models in the study of finance an growth is relatively recent. Two reference works in the literature are Gallegati et al. (2003) and Lima and Freitas (2007). Gallegati et al. (2003) build an agent-based model in which heterogeneous agents (firm and a bank) interact in the financial markets giving rise to complex dynamics. In their model, the bank's supply of credit is proportional to its current equity base which rises (lowers) if past profits were positive (negative) and it is independent on the rate of interest (the supply of credit is vertical). This set-up may create a domino effect in the case that a firm goes bankrupt. When the firm exits the market, it is not able to fulfil its debt commitments and, consequently, the bank's profit and equity base shrink. Less credit available means higher interest rate which means lower demand for investment and output. The model shows that, if the bankruptcies are spread out, the financial market may collapse and the real market comes to a halt.

Lima and Freitas (2007) develops an ABM in which the endogenous supply of credit-money by an adaptive banking system and the cash-flow of heterogeneous firms are modelled as co-evolutionary phenomena. In their model, the supply of credit-money is endogenous, demand-driven at the nominal interest rate, which is set by an adaptive banking system through a rule-of-thumb, satisficing procedure as a mark-up over the base rate, which is determined by the monetary authority. One of the consequences of this set-up is that, a rise in the default rate leads to a rise in the expected rate of default for the next period and, therefore, to a rise in the risk-adjusted banking mark-up for the next period increasing the interest rate in the economy. Differently from Gallegati et al. (2003), in Lima and Freitas (2007)' model firms are price-constrained not quantity-constrained in the credit-money market. The model shows that financial fragility is an emergent

dynamics in such a complex economy, with the distribution of the financing regimes of hedge, speculative and Ponzi across firms coming out as a spontaneous order.

Despite sharing some common features with both models described above, the model presented in section 3 differs from Gallegati et al. (2003) and Lima and Freitas (2007) in many important aspects especially regarding firms and the banking system behaviour. One key difference is that the present model makes the innovation process and the technical progress cumulative and endogenous. This allows us to analyse both phenomena of growth and business cycle, simultaneously. One of the main contributions of our work consists on the analysis of the pro-cyclical behaviour of the banking system, which may create growth or crisis depending on firms' interact with each other and with the financial sector.

## 3. The Agent-Based Model

The model simulates the evolution of an industrial sector where firms compete in improving their technology applied in the production process of a homogeneous good. The economy is populated by heterogeneous firms and by an adaptive banking system. Firms are heterogeneous in terms of price, resources devoted to R&D, sales expectation formation and financial fragility.

Firms are driven by competition through process innovation. In case firms cannot cover their production and R&D costs, they have to resort to borrowing from the financial sector. Since firms increase sales and gain market-share when their prices fall, labour saving innovation is key to reduce costs and increase market-share. Firms that do not or cannot innovate due to financial difficulties may lose sales, have their revenues reduced and enter a situation of financial fragility. Thus, poor innovative performance may send a previously financial healthy firm into a fragile position and be eliminated from the market as explained by Minsky (1982).

Given that firms might need to finance their operational cycle and R&D expenditure, there is no assurance, *a priori*, that their prices will generate enough revenue and profit to sustain their cash flow on the long-run. The complex environment that firms are in makes any long-run optimization behaviour impossible. The interactions among firms and of those with the financial sector may result in financial fragility and instability giving rise to business cycles and financial crises.

Revisei até aqui. Transferi um paragrafo desse início de seção para a conclusão, fazia mais sentido lá, talvez seja melhor deixar para apresentar as conclusões do modelo mais pro final da seção e na conclusão.

### 3.1. Production, Inventory and Demand

In order to concentrate the analysis on the interactions between firms, we assume that the economy produces a unique final good consumed by a representative household. On the production side, it is assumed that a pure labour economy, whose product is determined by the labour quantity hired at each time period. That said, it is assumed the following production function from Leontief and Strout (1963), $Y = min\{BK; AL\}$. The firm's production depends on the mobilized labour quantity and on the production technical coefficient $A_{i,t}$, which varies in time among the firms and depends, as well, on the R&D developed on each firm. Therefore, a firm $i$ will produce $X_{i,t}$ unities at time $t$ hiring $L_{i,t}$ units of labour with productivity gives by $A_{i,t}$, which increases as described ahead in sub-section 3.4:

$$X_{i,t} = A_{i,t}L_{i,t} \tag{1}$$

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In order to execute the production plan, the firm hires labour at time $t$ according to its expected demand for the period ($X_{i,t}^{Exp}$) and deducts the not planned inventory balance ($X_{i,t-1}^{S}$) that resulted in the end of the former period:

$$L_{i,t} = \frac{(X_{i,t}^{Exp} - X_{i,t-1}^{S})}{A_{i,t}} \tag{2}$$

Firms compute their expected demand based on the previous weighted average ($\varepsilon$) of past expectation and effective demand. Expected demand is an adaptive expectation behaviour which aims to smooth the short-term adjustment given by the following expression:

$$X_{i,t}^{Exp} = \varepsilon X_{i,t-1}^{Exp} + (1-\varepsilon) X_{i,t-1}^{Eff} \tag{3}$$

where if $\varepsilon = 0$ the firm promptly adjust its expectation using only the effective demand of previous time. The effective demand ($X_{i,t}^{Eff}$) depends on the aggregated demand which is distributed to the firms according to their market share ($ms_{i,t}$):

$$X_{i,t}^{Eff} = ms_{i,t} C_t^{Ag} \tag{4}$$

The market share, in turn, depends on the firm's individual competitiveness ($E_{i,t-1}$) which is defined by the equation (10) as will be explained in sub-section (3.2). When a firm produces more than their effective demand the excess is accumulated as inventory ($X_{i,t}^{S}$):

$$X_{i,t}^{S} = \begin{cases} X_{i,t-1}^{S} + X_{i,t} - X_{i,t}^{Eff} & \text{if} \quad X_{i,t} < X_{i,t}^{Eff} + X_{i,t-1}^{S} & \text{(5a)} \\ 0 & \text{otherwise} & \text{(5b)} \end{cases}$$

The difference between production and sales will affect the company's profit during the period and might even cause negative results. This scenery would force the firm to finance its cash flow on the banking system, in the case it does not count with enough accumulated profit to afford for it.

The aggregate demand ($C_t^{Ag}$) in the model is computed first and only after is distributed to the firms. It is a top-down procedure. Aggregate demand corresponds to the Marshallian function which depends on the aggregate income ($W_{t-1}$) and average price ($P_{t-1}$). Additionally, aiming to capture the effects of the financial sector on consumption, we separate the equation into two parts, where a share $1-\alpha$ is affected by variations in the interest rate. The reader can think this as a share of consumption of durables goods that depends on the credit, as documented by Erceg (2006).



Figure 1: Consumption and Interest Rate

$$C_t^{Ag} = \alpha \frac{W_{t-1}}{P_{t-1}} + (1-\alpha) \frac{1}{[1 + \psi_1(i_{t-1} - i_t)]^{\psi_2}} \frac{W_{t-1}}{P_{t-1}} \tag{6}$$

where the second term of equation (6) computes the effect of interest rate on consumption as a logistic process illustrated in figure (1). The parameters $\psi_1$ and $\psi_2$ control the shape of logistic curve[3]. The logistic shape capture the non-linear consumer's behaviour where the changing of consumption is small in the low and high interest extremes.
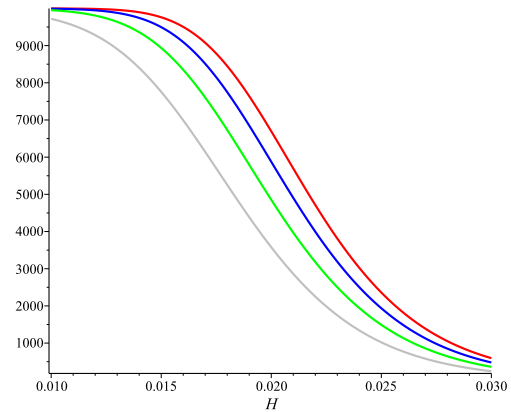
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[3]For the sake of simplicity we not control the consumer debt and just captures the negative effect of interest on a share of consumption in aggregated level. Impose an inter-temporal restriction in this point would add nothing relevant to the aggregated dynamics, rather than the fact of consumption will recover slowly after the crisis.

### 3.2. Price, Mark-up, Income and Firms profit

The firm's sales depends on its strategy of pricing and, therefore, its mark-up. The price is equal to marginal cost (wage) plus a mark-up rate $z_{i,t}$ as described by the following equation:

$$P_{i,t} = (1 + z_{i,t}) \frac{W_{i,t}}{X_{i,t}^{Eff}} \tag{7}$$

The mark-up must be sufficient to cover not only its unitary operational costs (basically wages) but its financial and technology development expenses too. An important connection between innovation and banking system is then established, which consequences to macroeconomic dynamics is far from a linear relation. In section 4, where the simulations are shown, we will come back to this with more details.

The mark-up rate is set by the firm's adaptive and interactive behaviour. One of the conducts that characterize this model as evolutionary and complex, along with innovation competition, is the fact that the firms adjust the mark-up on an adaptive matter, based on internal and external motives. The procedure used by firms is slightly richer than only setting a mark-up on the marginal cost as traditionally adopted in the literature. When setting the mark-up to attend internal motives the firm adjusts the mark-up according to the effective demand and financial expenses. When the effective demand is higher then previous production and stock the mark-up is set up; if a firm run on debt caused by the low performance in the market, it tries to increase the mark-up to afford for the debt and interest in the next periods, and the opposite. However, this mark-up cannot be feasible when confronted with the market, as it can stand(???) very high or very low. The best price strategy for the firms is to set the price a bit higher or lower than the average of their main competitors. In order to win the competition a firm just need to run ahead but not very far from its competitors. If it falls behind, the best thing to do is avoid staying far behind or coming last(???). The mark-up procedure runs into two-step(??), first computing internal motives according to equation (8) and then adjusting the result by a factor $\rho$ according to equation (9):

$$\check{z}_{i,t} = \frac{\Delta z^{dem}}{\left[1 + \varrho_1 \exp\left(-\varrho_2 \left(\frac{X_{i,t-1}^{Eff}}{X_{i,t-1} + X_i^S} - 1\right)\right)\right]^{\varrho_3}} + \frac{\Delta z^{fin}}{\left[1 + \varrho_4 \exp\left(-\varrho_5 (DF_{i,t-1} - f)\right)\right]^{\varrho_6}} \tag{8}$$

$$z_{i,t} = \begin{cases} (1 + \rho + \check{z}_{i,t}) z_{i,t-1} & \text{if } P_{i,t-1} \leq \bar{P}_{4,t-1}, \\ (1 - \rho + \check{z}_{i,t}) z_{i,t-1} & \text{if } P_{i,t-1} > \bar{P}_{4,t-1} \end{cases} \tag{9}$$

where $\varrho_{1\ldots6}$ and $f$ are constants and $\Delta z^{dem,fin}$ is the changing value of mark-up according to internal demand and financial motive, which we hope to be near 0.01 to 0.05 in the simulations[4]. The supposition is that the firms realize a price research together with *four* other companies[5] randomly selected and register the average price. In case of the price bigger than the average price ($\bar{P}_t$), the firm will reduce its mark-up for the next period to $(1 - \rho)$. In case of the price is smaller, it will upgrade the mark-up previously calculated in $(1 + \rho)$, where $\rho > 0$. This interaction among firms on price setting, an absent mechanism on the models with representative firms, allows the firm to adjust its mark-up to the market conditions as a whole at the same time it avoids extreme decisions. Although the firm looks for differentiating itself on the market price, it will be always monitoring its concurrence to avoid excessive price downgrades, mainly in the case of a drastic innovation that could produce a large productivity growth.

Once the company has defined its mark-up and consequently its price, we can compute the market share ($ms_{i,t}$), that is, the portion of the aggregated demand ($X_{i,t}^{Ag}$) that it is up to each firm incumbent. The

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[4]Due to cumulative computation with more than 500 time steps, a high change of the mark-up generates large variance and sometimes explosive prices and monopoly, a result to be avoided.

[5]The exact number of companies is not crucial to determine the results, one can admit any number or even the comparison with the average market price.

market share conquest depends on the firms market competitiveness, defined as being the inverse of the firms, as follows:

$$E_{i,t} = \frac{1}{P_{i,t}} \tag{10}$$

The individual competitiveness is equal to the inversion of the price ($E_{i,t} = 1/P_{i,t}$), whereas the average competitiveness is equal to the weighted average of the individual competitiveness, whose weighing factor is the individual market share (Dosi et al., 1994).

We may then calculate the market share assuming that one firm will own a bigger portion of the market, in case that its price is below the average price of the market, and will count with a smaller market share if the price is above the average, as defined by the equation (11):

$$ms_{i,t} = \left[ 1 + \beta \left( \frac{E_{i,t-1}}{\bar{E}_{t-1}} - 1 \right) \right] ms_{i,t-1} \quad \text{and} \quad 0 < \beta < 1 \tag{11}$$

where $\beta$ is a common parameter to the firms that measure the market share sensibility to the competitiveness (price) grade. As bigger the $\beta$ is, the more the firm gain market if its price is below the average and vice-versa.

After defining its price and its market share, the firm will be able to calculate its revenue and operational costs and, in the end, its profit. The firm's total revenue is decomposed of operational and financial revenue, which is the total received interest over its accumulated profits remunerated by the primary interest rate. The total costs are composed by the operational cost (in this model exclusively wages), expenses on research and, at last, the financial expenses over the accumulated debt. Thereby, the firm's total profit at the end of the period $t$ will be:

$$\Pi_{i,t} = (R_{i,t}^O + R_{i,t}^F - W_{i,t} - R\&D_{i,t} - i_t D_{i,t-1}^S) \tag{12}$$

On the profit equation (12), $R\&D_{i,t} = \varphi_i \Pi_{i,t-1}$ is the profit percentage that the company destine to research and development on innovation at each period of time. $R_{i,t}^O$ is the firms operational income, $R_{i,t}^F$ is the financial income from the accumulated profits application on the beginning of period $t$, already subtracted the expenses on $R\&D_{i,t}$, $W_{i,t}$ is the wages total value or the total variable costs, $i^*$ is a nominal interest rate charged by the banks on credit operations and $D_{i,t-1}^S$ is the balance or the debt amount of the firm on the last period.

### 3.3. Labour and Wage

The labour market is a second instance that makes this model complex. The wage bargain depends on the firm productivity and its success to innovate and depends on aggregated average wage. Once the technological change is taken into account, technological improvements that lift labour's productivity will affect the profitability and the financial fragility, because it affects the unitary costs of labour and, therefore, the competitiveness. Indeed, this influence becomes more intense and complex when the technological innovation is higher.

While productivity and amount of labour are set at level firm, according to its innovation capability and production plan, the average wage paid by a firm depends on the interactions among firms as a aggregated pattern. Since the average wage is the same for all firms, they are affected by the macroeconomic environment. Notwithstanding, if a firm succeeds to innovate it is facing a decision about fire some workers, that is, reduce $L_{i,t}$ and maintain the production plan, or maintain the workers and expand the production. This is an implicit mechanism behind the equation (13), if the firm's productivity is higher than the average its strategy is to pass a share $\varpi$ of gaining productivity along to workers. This boost the aggregated and per capita income and consumption in the long-run, generate economic growth and helps to avoid technological unemployment. On the other hand a firm with low productivity can face financial problems due to high labour cost imposed by a high average wage.

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The total labour cost of the firm ($W_{i,t}$) is really the only production cost involved and depends on the fixed (constant) unit nominal wage ($V$), labour's average productivity ($\bar{A}_{i,t}$) and quantity of labour hired by the firm ($L_{i,t}$), as described by the following equation:

$$W_{i,t} = \begin{cases} V\bar{A}_t L_{i,t} & \text{if} \quad A_{i,t} - \bar{A}_t \leq 0 \\ V[\bar{A}_t + \varpi(A_{i,t} - \bar{A}_t)]L_{i,t} & \text{if} \quad A_{i,t} - \bar{A}_t > 0 \end{cases} \tag{13}$$

where the unitary nominal wage ($V$) is constant and set at the beginning of a simulation and $\varpi$ is a parameter that regulates the "gift-wage", that is, the portion of productivity gap that will be passed to wage. According to equation (13), a high productive firm pays higher salary while the low productive firm pays lower one. The equation is richer than its simple semblance and conducts to heterogeneous wages among the firms. It is consistent with the idea of "labor contracts as partial gift exchange" due to Akerlof (1982) who named it as "four paradigm" or "equity theory" of social exchange theory (Akerlof, 1984, p. 82, 83)[6].

### 3.4. Innovation and Productivity

The Schumpeterian technological competition is the third channel through the complexity flows. The complexity is activated by strong interaction at the firm level, meanly while firms try to imitate the competitors or compare yourself and react to the average productivity. The innovation process, in this model, may occur from three different sources: from a learning by doing cumulative process (Arrow, 1962b), from imitation and from innovation (Nelson and Phelps, 1966; Nelson and Winter, 1982). The simultaneous use of this three vector has been recognized by the literature as an important feature of Schumpeterian technological competition (Segerstrom, 1991; Geisendorf, 2009). The firms are simultaneously searching for new innovation from the three origins, but just implement the best one choosing the maximum productivity available, according to equation (19).

The first innovation channel, the learning-by-doing process, happens when the productivity raises in response to increased production. This process of productivity growth has been called in the literature as the "Kaldor-Verdoorn Law", from the works of Verdoorn (1949) and Kaldor (1961) and later algebraically generalized by Arrow (1962b). This idea is represented on the equation (14), where the technological change by learning depends linearly on the production growth:

$$A_{i,t}^{LD} = \delta_1 \frac{\dot{X}_{i,t-1}}{X_{i,t-1}} \quad \text{if} \quad \dot{X}_{i,t-1} > 0 \tag{14}$$

where $\delta_1$ is the Kaldor-Verdoorn coefficient[7], $A_{i,t}^{LD}$ is the technological change by learning and $\dot{X}_{i,t}$ is the growth of the production between the period $t-2$ and $t-1$. Additionally, $A_{i,t-1}$ is the firm's productivity on $t-1$. The parameter $\delta_1$ represents the sensibility of the labour's productivity growth to the relative production variations, which is exogenous and common to all firms. The restriction $\dot{X}_{i,t} > 0$ imposed on equation (14) implies that eventual negative variations on production do not turn itself on technological unlearning.

The second source of productivity change is imitation. This type of innovation is stochastic and local. One can suppose that the imitated technology has tacit components and that the firm's imitation capacity is limited, thus only a proportion of the difference among the imitated firm's productivity will be copied. In the equation (15), the production technology obtained by imitation is the result of the random research on three concurrent firms.

$$A_{i,t}^{IM,max} = \max(A_{1,t-1}^{IM}, A_{2,t-1}^{IM}, A_{3,t-1}^{IM}) \tag{15}$$

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[6]According to Akerlof (1982) a firm can give a "gift" to workers paying them with an extra wage. In our case, the "gift" is given by productive firms in the form of wages in excess over average wages, as described in the second part of equation 13.

[7]The so-called Kaldor-Verdoorn's "Law" is essentially a correlation among productivity and aggregated demand originated from the macroeconomic plan. Although the equation (14) applies this correlation on the microeconomics plan, the aggregated relation is preserved.

Once the imitated firm is chosen, the next step defines how much productivity will be imitated and that depends on the technological distance among the imitator and the imitated firm, as shown by the following inverse logistic function:

$$A_{i,t}^{IM} = \Delta A_{i,t}^{IM,max} \left[ 1 - \frac{\delta_2}{\left(1 + \delta_3 \exp(-\delta_4 \Delta A_{i,t}^{IM,max}\right)^2} \right] \quad \text{if} \quad P_{i,t}^{IN} \geq RND \tag{16}$$

where $\Delta A_{i,t}^{IM,max} = A_{i,t-1}^{IM,max} - A_{i,t-1}$ is the technological distance, $\delta_{2,3,4}$ are constant which helps to control how perfect will be an imitation, and $P_{i,t}^{IN}$ is the innovation probability, discussed right after. The functional form of the equation (16) captures the technological distance effect. A firm that is able to imitate may not do it perfectly and may go through larger difficulties in giving a technological "jump". This difficulty shall be larger as more the imitator's productivity differs from the imitated firm. The Neperian term's exponents capture the distance effect of which follows an inverse logistic process. The logical condition states that the imitation will happen only if a probability computed by equation (17) is higher than a uniform random number $RND \in [0,1]$.

The third source of technological change is the creation of a new productive process. Like the second source, the new process is computed as two stages stochastic process. The first stage consists in to compute the success or failure of the innovation discovery according to a probabilistic function (17). If the event is successful we move to the second step to compute the productivity growth which follows a generalized logistic function[8], according to (18).

On the equation (17), the innovation probability follows an exponential inverse process and depends on R&D expenses and from the past productivity. The amount that a firm expense in R&D depends on a share of profits, so, $R\&D_{i,t} = \varphi_i \Pi_{i,t}^S$.

$$P_{i,t}^{IN} = \frac{\gamma_0}{\left[1 + \gamma_1 \exp\left(-\gamma_2 R\&D\right)\right]^2} \quad + \quad \frac{\gamma_0}{\left[1 + \gamma_3 \exp\left(-\gamma_4 A_{i,t-s}^{time}\right)\right]^2} \tag{17}$$

where $\gamma_{0...4}$ are parameters that able to adjust the probability sensibility on innovating in relation to the R&D expenses and $A_{i,t-s}^{time}$ is the time elapsed since the last new innovation in time $s$.

When a innovation occurs the new firm's productivity will be given by normal distribution with the average $A_{i,t-1}$ and variance $\sigma_2^2$. This result is only used if the innovation probability ($P_{i,t}^{IN}$) as calculated by (17) is larger or equal to a quasi-random number generated by a uniform probability distribution function that varies between 0 and 1. The productivity of new innovation is, therefore, calculated as:

$$A_{i,t}^{IN} = \begin{cases} Norm(A_{i,t-1}\sigma_2^2) - A_{i,t-1} & \text{if} \quad P_{i,t}^{IN} \geq RND[0,1] \\ 0 & \text{if} \quad P_{i,t}^{IN} < RND[0,1] \end{cases} \tag{18}$$

The firm's effort to innovate simultaneously through the three fronts, learning by doing, imitation and innovation, place the firm face a decision about what is the best decision each time step. A firm will choose the maximum productivity available:

$$A_{i,t} = A_{i,t-1} + \max(A_{i,t-1}^{LD}, A_{i,t-1}^{IM}, A_{i,t-1}^{IN}, 0) \tag{19}$$

### 3.5. The Financing of the Firm and the Banking Sector

The connection between finance and growth has been largely analysed in theoretical and empirical literature since the early years but has received a great deal of attention in the last two decades. Recent empirical analysis has concluded that there are bi-causality in rich and medium income countries while one-way causality from growth to finance for the poorest and, therefore, that a "well-functioning financial system

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[8]This is a standard way to proceed and has been widely used in innovation literature as in Nelson and Winter (1982), Valente and Andersen (2002) and many others.

is a necessary but not sufficient condition to reach steady state economic growth" (Hassan et al., 2011)[9].
This is the exact situation we introduce in the model. In the long-run growth is boosted by innovation but the existence of an active financial system helps firms manage his cash-flow given them breathe to survive during a short time avoiding a quick bankrupt and damping volatility. But, at the same time, the endogenous pro-cyclic behaviour of the banks can intensify and spread a local crisis to the whole economic system, making the dynamics complex and subject to a threshold rather than linear relationship.

In order to analyse the evolution and the effects of the changes on the financing regime of the firm over the economic cycle, the firms in this economy, aside from the productive activities, pricing and R&D, has to make a decision whether borrow money from the banks to finance its cash-flow or not. We assume that only the firms with negative cash-flow perform loan in banks. The operation is contracted only for a short period and, in case the firm does not count with enough profit to cover the debt service and/or the loan amortization, a new credit operation is then contracted on the next period until the firm is able to eliminate its debt.

On the other hand, it is sufficient for our proposal, assume that the financial sector is formed only on a banking firm, what is equivalent to assume a representative agent in the financial sector. In doing that, we use the same arguments launched originally by Schumpeter (1939, p. 107 and following) simplifying and restricting the financial sector to a "credit creation by the bank". Equations (20) to (24a) formalise the mechanism through which the banking system finances the firms. The deposit interest rate ($i^*$) is the rate banks pay firms on their accumulated profits invested in the financial system. In the present model, the deposit interest rate is assumed to be constant and exogenous. The lending interest rate ($i_t$) is the rate charged by banks for loans to firms. The difference between the two rates ($i_t - i^*$) is the net interest spread. This mechanism assumes an endogenous money supply in the sense of Kaldor (1982, 1985) and Moore (1988). This approach to the money supply is also known as the "horizontalist approach", according to which banks are passive and adjust the quantity of money to a given interest rate, money has an infinity elasticity of supply. Therefore, credit is restricted by means of price (the interest rate) not quantity.

The supply of credit is endogenous and determined by the firm's demand for credit. The firm's demand for credit is equal to its losses or negative profits $D_{i,t} = \Pi_{i,t}^-$. A firm's negative profit needs to be covered by bank loans. Since all the firm's losses automatically become debt, the firm's accumulated debt $D_{i,t-1}^S$ is equal to its accumulated negative profit. The economy's aggregate demand for credit (also the economy's total debt) in period $t$ is calculated by the sum of all the individual firms' demand for credit, formally given by:

$$D_t = \sum_{i=1}^{F_t} \Pi_t^- \tag{20}$$

The lending interest rate for the loan operations is calculated by applying a mark-up ($h_t$) over the deposit interest rate, according to the following equation:

$$i_t = (1 + h_t)i^* \tag{21}$$

Banks set the lending interest rate ($i_t$) based on their evaluation of the economy's degree of indebtedness. Once set, it is applied to all firms, independently of their individual degree of indebtedness. The banks' mark-up ($h_t$) is adjustable and might change from one period to the next depending on a loan payment default indicator ($d_t$), which is the ratio of the economy's total debt to its total accumulated profits,

$$d_t = \frac{\sum\limits_{i=1}^{F_t} \Pi_t^-}{\sum\limits_{i=1}^{F_t} \Pi_t^S} \tag{22}$$

The risk adjusted banking mark-up is given by the following logistic equation:

$$h_t = \frac{h^{max}}{[1 + \theta_1 \exp(-\theta_2 d_{t-1})]^{\theta_3}} \tag{23}$$

where $h^{max}$ is the maximum mark-up set by the banks and $\theta_1, \theta_2, \theta_3$ are parameters that control the sensibility of the mark-up to the degree of risk perceived by the banking system at each period, in a logistic equation. It is assumed that $h^{max}$ is exogenously fixed. This functional form avoid explosive interest rate. If $i^* = 1\%$ and $h^{max} = 2\%$, for example, we allow interest rate triplicate. An increase in the default rate at any period raises the expected default rate for the next period. Banks react by increasing their risk adjusted mark-up for the next period. Empirical evidence for this behaviour may be found in Angbazo (1997), Saunders and Schumacher (2000) and Brock and Rojas-Suarez (2000).

When the ratio Debt/Revenue of a firm is higher than the aversion risk parameter set by financial sector $\chi$, the firm is not able to honour the principal and interest payment and the firm runs to bankrupt. According to this rule, a more developed and robust financial sector could be more tolerant, taking more risk and giving breath to firm try a saviour innovation, by increasing $\chi$:

$$FirmExit_{i,t} = \begin{cases} 1 & \text{if} \quad Debt_{i,t}/RT_{i,t} > \chi, & \text{(24a)} \\ 0 & \text{otherwise} & \text{(24b)} \end{cases}$$

The present ACE model, though having a relatively simple general structural, being comprised of a number of heterogeneous firms grouped in sectors and a pool of identical financial institutions, due to its evolutionary behaviour and complex interactions, is capable of producing interesting emergent macroeconomic dynamics.

## 4. Combinations Between Technological and Banking Financing Regimes: a simulated macro analysis

To investigate how growth and cycle respond to combinations between the different technological and financing regimes we run a bunch of simulations[10] including a test of the robustness and analyse the macro dynamic resulting from the large-scale interactions between firms/firms and firms/bank.

The macrodynamic robustness (section 4.1) is demonstrated by computing 100 simulations (runs) and taking the average trajectory and the dispersion of each one of this 100 individual trajectory. This part of the experiment runs the same initial condition and parameters configuration 100 times changing only the seed of the random variables. The initial conditions and parameters at this stage characterize the *baseline* scene which will be referred as *Low Technological* (LT) regime combined to a *Low Financial* (LF) profile producing an LL combination, first L for technology second for finance. The robustness analysis shows a well behaved model with similar paths for main aggregated variables.

Given that robustness, in section (4.2) we investigate the macrodynamic of four configurations emerging from the combination of two technological (low/high) and two financial regimes (low/high), giving rise to four macroeconomic regimes:

(i) LL: This is a combination of low technological capabilities and low financial response. Low technological regime is defined as a lower probability to innovate by setting low values for parameter $\gamma_0$=0.1 and parameters $\gamma_{1,2} = \{8, 0.1\}$. A low financial profile in this model means a lower tolerance to firm indebtedness by setting a low value for parameter $\chi = 5$ (see equation 24a) and high elasticity of interest rate related to the default index (parameter $\theta_2 = 200$) and high upper limit of interest by setting $h^{max} = 4$ (according to equation 23). All together this means a risk averse and hostile financial sector from the firm's viewpoint. Financial sector is intolerant to indebtedness and reacts roughly by increasing quickly the spread over basic interest and pushing it to a higher level;

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[10]The simulations was run using the software Laboratory for Simulation and Development-LSD developed by Valente (2008).

(ii) HH: This regime is a combination of high technological capabilities and an active but tolerant financial sector. In HT regime the innovation parameters take higher values, like $\gamma_0$=0.4 and $\gamma_{1,2} = \{32,\ 0.4\}$ which cause to boost innovation and accelerate the economic growth and technological competition between firms. In the HF regime financial sector is tolerant to indebtedness allowing for $\chi = 20$ and reacts softly by increasing slowly the spread over basic interest with $\theta_2 = 50$ and at the same time setting a small upper limit of the spread interest with $h^{max} = 1$). For the economic growth and cycles perspective this is the more virtuous regime since it can generate high growth rates with short and small cycles when compared with HL regime (more about these regimes in section (4.2);

(iii) LH: The LH regime is a combination of low innovation and therefore low economic growth with an unfriendly financial regime. Intuitively we hope that a crisis can emerge at some special occasion when the averse risk financial sector rides roughshod over firms. In this case, even the closeness between firms due to the low innovation rate is not able to avoid a crisis;

(iv) HL: The last regime is characterized by an innovation intensive economy facing an low finance regime where the financial sector is intolerant and risk averse. This regime is able to produce more acute economic cycles since the innovation rate is higher forcing the technological competition increasing the number of lagged firms which will face cash flow restrictions. The rough financial sector behaviour spreads and intensifies the crisis coming locally from the productive side.

### 4.1. Baseline configuration and robust macro dynamics

The first experiment consists of 100 simulations (runs) over 1000 time steps with different random seeds, computed using the LL regime. The time-line is a bit abstract, one time step means a time during which all the firms have the opportunity to make a decision to adjust their behaviour in the market as a response to the state of the world in $t - 1$.

The robustness analysis is a necessary step when we are faced with a complex environment. One feature of a complex system is the cumulative causation and path-dependence, where small change in a time step can shift smoothly or radically the course of the economy for ever. Many of this trajectories can be near or similar, but eventually may differ a lot. Furthermore, the system may exhibit sudden changing in the dynamics subject to a threshold generated by the collective behaviour of the agents (Granovetter, 1978). If we were in a deterministic world we would get only one trajectory, or if we were in a probabilistic world we could observe at the best many trajectories constricted inside a range previously delimited by a probability density function, all them moving toward an equilibrium in the long-run as happens, for instance, with dynamic stochastic general equilibrium models (DSGE). This cannot be the case here due to the immanent complexity and the opened, and therefore blinded, future. Notwithstanding, controlling for random seed, the random dynamics can be reproduced at any time. In order to test whether the trajectories are similar, we plot the average and individual values of the different aggregated variables against the time. The baseline configuration of LL economic regime is shown in the table (1) and the aggregated results are shown in figure (2).

At the beginning the economy is populated by 100 equal firms, each of them with 1% of market share, same technology $A_{i,t=0} = 1$, same mark-up $z_{i,t=0} = 0$, accumulated profits \$2000, price and unitary wage equal to \$2.00 and no inventory. The symmetric initial condition also resembles the Walrasian environment where all participants set the same competitive price, harvest zero profit (mark-up zero) and have equal power market. This initial symmetry will allow us to assess how this isomorphic topological condition can be broken by technological competition and how the microeconomic level reacts when interacting with the financial sector, under the different technological regime. The breaking of symmetry shows how artificial the Walrasian tatonnement is, as stretched at length by Gintis (2000), Bowles and Gintis (2000) and Bowles (2001). At the firm level, the positive accumulated profit at the beginning is a conservative assumption which makes firms more resistant in the firsts rounds of technological competition postponing their need to borrow money and even its bankrupt when it is the case. This is not central for the analysis. At the macroeconomic level, the aggregated consumption and production is set in 100.000 units what means to say that monetary demand and product is \$200.000. The basic interest rate is $i^* = 1\%$ and we allow the rate

Table 1: Parameters of LL Economic Regime - Baseline

| Parameter | Symbol | Equation | Base Line |
|---|---|---|---|
| Weight of demand expectation | $\varepsilon$ | 3 | 0.8 |
| Share of $C$ not affected by $i$ | $\alpha$ | 6 | 0.8 |
| Elasticity of $C$ to $i$ | $\psi_1, \psi_2$ | 6 | 2.0, 3.0 |
| Change Mark-up by demand motive | $\Delta z^{dem}$ | 8 | 0.01 |
| Change Mark-up by finance motive | $\Delta z^{fin}$ | 8 | 0.01 |
| Elasticity Mark-up to demand | $\varrho_{1,2,3}$ | 8 | 8, 40, 3 |
| Elasticity Mark-up to finance | $\varrho_{4,5,6}$ | 8 | 0.10, 0.20, 3 |
| Elasticity Mark-up to finance | $f$ | 8 | 100 |
| Adjustment Mark-up to competitors | $\rho$ | 9 | 0.1 |
| Market share sensibility to price | $\beta$ | 11 | 0.05 |
| % Profit spent in R&D | $\varphi$ | 12 | 0.05 |
| Gift wage | $\varpi$ | 13 | 0.95 |
| Coef Kaldor-Verdoorn | $\delta_1$ | 14 | 0.5 |
| Productivity of imitation | $\delta_{2,3,4}$ | 16 | 0.8, 5, 100 |
| Prob. of innov. upper limit | $\gamma_0$ | 17 | 0.1 |
| Prob. of innov. due to R&D | $\gamma_{1,2}$ | 17 | 8, 0.1 |
| Prob. of innov. learning effect | $\gamma_{3,4}$ | 17 | 10, 0.15 |
| Variance of innovation | $\sigma_2^2$ | 18 | 0.01 |
| Elasticity of spread to debt | $\theta_{1,2,3}$ | 23 | 5, 200, 3 |
| Spread maximum of bank | $h^{max}$ | 23 | 4 |
| Debt/Revenue ratio | $\chi$ | 24a | 5 |

increases by a multiple $i \in [1,5]$ during a crisis[11]. The initial bank mark-up is 0%.

The result shows a consistent macrodynamic pattern with baseline configuration comparing this 100 trajectories so that we can refer to the average as the representative trajectories for all variables. In other words, we could take just one or few simulations rather than a hundred average as a representative dynamics without fall in a solemn damage.

The macrodynamic which emerges from the large-scale interaction at the firm level is illustrative of an important propriety of this interacting environment. While firms start with high accumulated profits and are able to adjust its price and innovation effort to win or survive under the pressure of market competition, a financial crisis emerges near the step 250 melting the production down as shown in figure (2b), even while no previously specified equation induce this result. The cause of this phenomenon is the technological competition among firms and its cumulative consequences. The interactions along the time provide many opportunities for firms to deal with price and innovation to adapt itself evolutionarily and to avoid the bankrupt and in the best case to win the race. The race is flexible and positions can change over time. That is why some firms open large advantage, another fall behind and bankrupt and many stays live without growing as fast as the frontier. The winner at the beginning does not remain at the top of the podium and eventually can be exceeded by the competitors. Bankrupt by failing in innovation competition would be an isolated case, but when lagged firms accumulate debt and systemic risk reaches a threshold, figure (2e) and (2f), the reaction of financial system increasing interest rate can drag the second wave of fragile but viable firms, pushing down all economy. A generalized crisis sets in. The crisis here emerges from the confluence of two drivers: technological heterogeneity coming from Schumpeterian competition and firm funding by the financial sector. The financial market has a double role: it helps to make market stable and even propel the innovation, but when a crisis emerges, the financial sector disseminate the crisis to all economic system, more quick and deep when a share of aggregated demand is affected by the interest rate, according to equation (6). The financial sector works pro-cyclically as argued by Minsky (1982). The detail of this general history

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[11]In fact we compute the sum $i_t = (1+h)i^*$ where $0 \le h \le h^{max}$ and $h^{max} \in [1,4]$.

will be discussed in the following sections.

Another important aspect of the model is that it provides the evolutionary micro-foundations (see Cimoli and Porcile, 2015) of the phenomenon of growth and cycles under technological competition and endogenous funding by a banking credit creating mechanism.

Figure 2: Individual and Average Trajectories of 100 runs



(a) Productivity

(b) Product

(c) Mean Price

(d) Number of Firm

(e) Risk (d)

(f) Interest Rate (H)
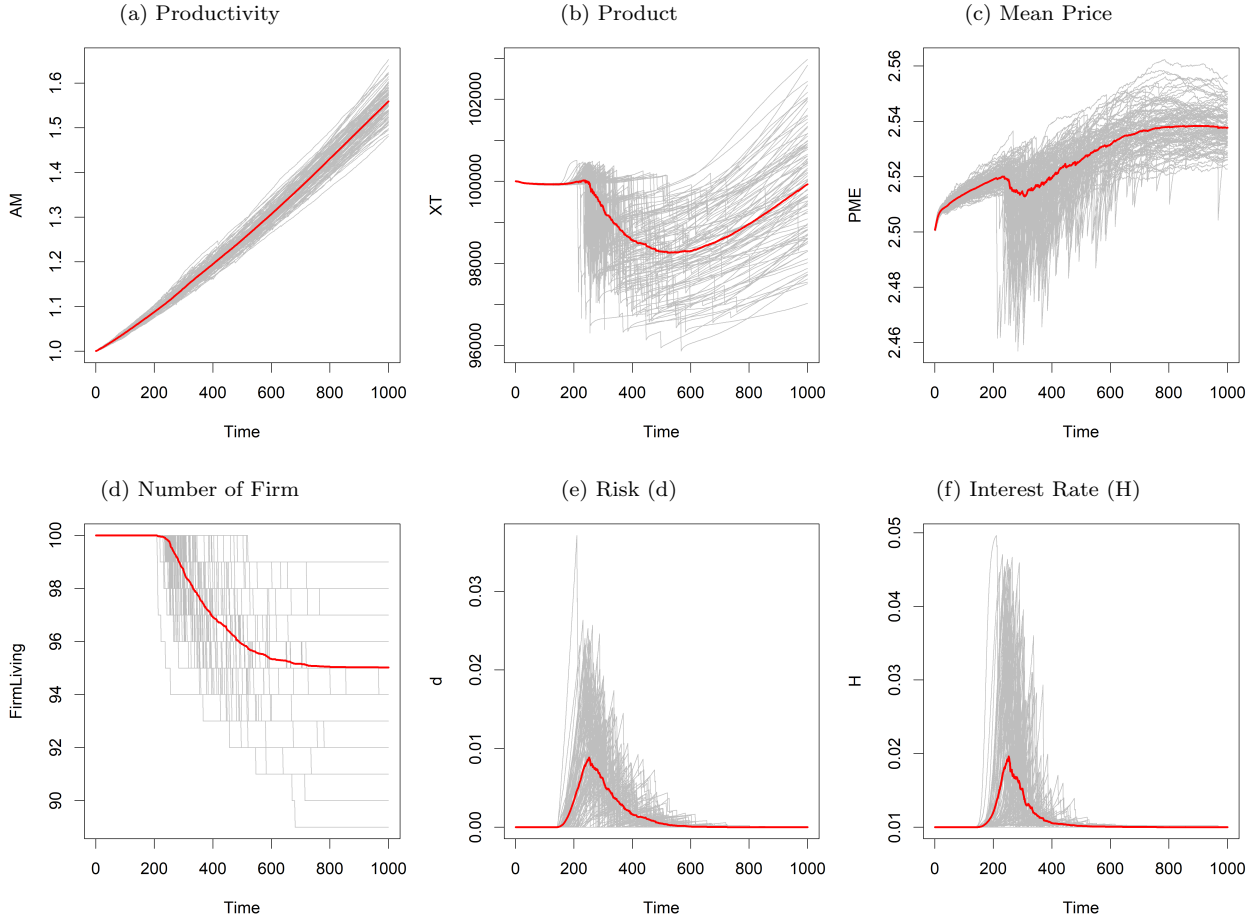
## 4.2. Interactions Between the Technological and Banking Financing Regimes

Given the robustness of results, we move to the main analysis made possible by the model. Departing from the baseline simulation, characterized as a combination between Low Technological regime and Low Financing regime (LL), we change a restricted set of parameters to demarcate four economic regimes. We then run 10 simulations for each of the four regimes and take the average results plotting the trajectories of macroeconomic variables in the figure (3).

The question here is whether the interactions at firm/firm and firm/bank level in different regimes have distinct consequences in the economic dynamics. We look for understanding some major theoretical questions: 1. what is the anatomy of growth and cycles in each regime; 2. how technological competition and financial regime can be combined to promote more stable dynamics and high long-run growth.
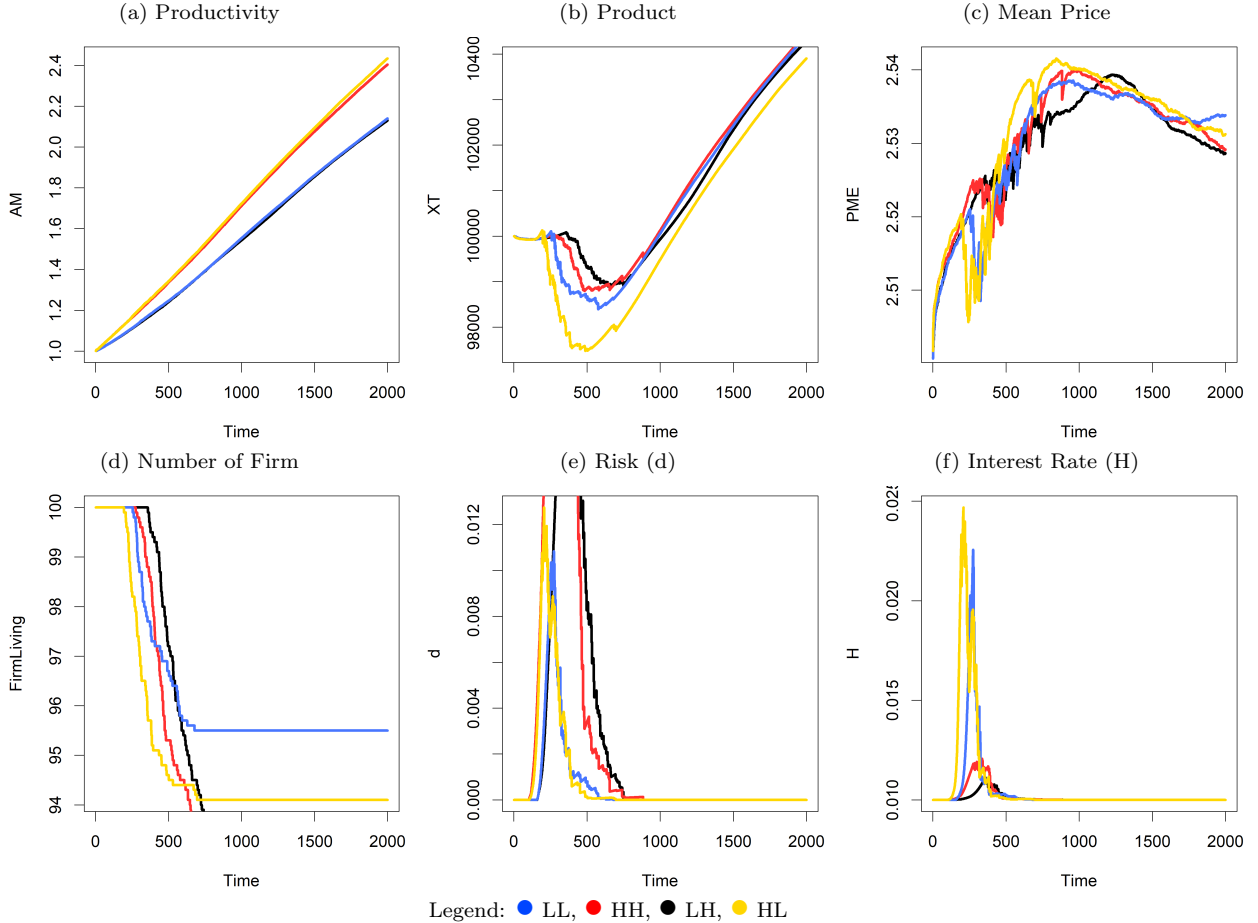
The whole landscape of the four regimes (LL, HH, LH, HL) helps to understand what is going on. First of all, instability is an immanent property of such regimes, since all of then incur in crisis around period 250, but with different intensity and time delay. Of course, eliminating the financial sector and decreasing

Table 2: Parameters for Four Economic Regime

| Parameter | Symbol | Eq. | LL | HH | LH | HL |
|---|---|---|---|---|---|---|
| Coef Kaldor-Verdoorn (Learning) | $\delta_1$ | 14 | 0.5 | 0.5 | 0.5 | 0.5 |
| Productivity of imitation | $\delta_2$ | 16 | 0.8 | 0.8 | 0.8 | 0.8 |
| | $\delta_3$ | 16 | 5 | 5 | 5 | 5 |
| | $\delta_4$ | 16 | 100 | 100 | 100 | 100 |
| Prob. of innov. - upper limit | $\gamma_0$ | 17 | 0.1 | 0.4 | 0.1 | 0.4 |
| Prob. of innov. due to R&D | $\gamma_1$ | 17 | 8 | 32 | 8 | 32 |
| | $\gamma_2$ | 17 | 0.1 | 0.4 | 0.1 | 0.4 |
| Prob. of innov. learning effect | $\gamma_3$ | 17 | 10 | 10 | 10 | 10 |
| | $\gamma_4$ | 17 | 0.15 | 0.15 | 0.15 | 0.15 |
| Variance of innovation | $\sigma_2^2$ | 18 | 0.01 | 0.01 | 0.01 | 0.01 |
| Elasticity of spread to debt | $\theta_2$ | 23 | 200 | 50 | 50 | 200 |
| Spread maximum of bank | $h^{max}$ | 23 | 4 | 1 | 1 | 4 |
| Debt/Revenue ratio (Exit threshold ) | $\chi$ | 24a | 5 | 20 | 20 | 5 |

Figure 3: Average Trajectories by Economics Regimes-10 runs



(a) Productivity  (b) Product  (c) Mean Price
(d) Number of Firm  (e) Risk (d)  (f) Interest Rate (H)

Legend: ● LL, ● HH, ● LH, ● HL

the innovation rate for a minimum level could make the economy stable operating nearly the hypothetical circular flow. That could be a theoretical concern but far from the reality of many countries, mainly the developing and developed ones which are constantly disturbed by innovation and financial shocks. Such

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immanent instability has been recognized by many, but mainly Minsky (1982, 1993) and Eichengreen (2004) to quote some. Second, the interactions between the productive and financial system play a significant role in such macroeconomic dynamics. Micro-behaviour of Schumpeterian competitive firms interacting with each other fuelled by cash-flow financing is part significant of the history of the growth, cycles and crisis.

What shows up at our figure (3) is illustrative of this macro-dynamic pattern. According to the figure (3b and 3c) in regime HL (orange trajectories) both variable, product and price, perform higher cycles. Remember that the low financial regime is more intolerant and hostile from the firm's viewpoint since it is risk-averse and will not tolerate high indebtedness degree. Aversion to risk or a fragile financial sector which reacts strongly to real business cycles helps to intensify the crisis. During the recessive phase of the cycle, product reaches a deeper point compared with other regimes and do not restore the previous tendency. It is a permanent shock, despite a partial and accelerated recovering just after the minimum point.

But the trajectory changes significantly when we maintain the rhythm of the innovation but combine it with a more friendly financial regime like the HH case (red), which we interpret as mature or developed system. Both product and price oscillate less and in the long-run and the economy reaches a higher level of income. Crisis can be attenuated comparing HH with HL regime. If we consider that a more developed financial sector is able to finance indebted firms and not to charge them a lot, then a HH is preferable. Rather than normative concerning at the moment, we are interested in investigating how does this happen? Some micro-economic reasoning is necessary to better understand the point, and an agent-based model is useful in this case. In a high friendly financial regime bank finances, the firms with negative cash flow for a longer time compared with the low financial regime, tolerating a higher Debt/Revenue ratio ($\chi = 20$ rather than 5 in the low regime), and punish less the indebted firms with a lower interest rate. This is sufficient to give breath to a lagged firm who eventually find a profitable innovation that will throw it near the technological frontier. Although we do not intend to depict all the micro-dynamics since our proposal here is to explore the macro consequences of innovation and finance interactions for growth and cycles, the understanding of the evolutionary micro-foundations is crucial for the results. Schumpeterian firms are engaged in a permanent search for increase productivity exploring simultaneously three front, learning by doing, imitation and innovation. Learning by doing process ceases to produce effect during the recession, in the case that $A_t^{LD} = 0$. Imitation and innovation decrease since the profit is lower but remains producing positive effects which allow for fast recovering.

The HL and HH regimes show the cases where economy is intensive in innovation. How does the anatomy of less innovative economic growth and cycles look like, compared with a highly innovative, in both cases, with a low and high developed financial sector? Contrasting the LL (blue) with LH (black) regime can be illustrative. They differ only by the financial sector so that the different trajectories observed can be explained by the financial side. While the productivity (see figure 3a) is equal the product growth and cycle (figure 3b) differ during the recession phase but converge in the long-run. Product and business cycles thus diverge only by financial motives. According to the model in low technological regime financial sector play a major rule during the crisis or business cycles rather than long-run development. Considering that a share $(1 - \alpha)$[12] of the aggregated consumption is financed by the bank and a developed financial sector is more parsimonious to adjust the spread the demand helps to attenuate the business cycle at the same time as firms can, as explained before, take a breath and try to innovate. But differently than before, now the probability of innovation is low so that innovation is not a strong drive for recovering. In low technological regime, the relationship between aggregated demand and financial sector is more important than supply side, since firms do not accumulate great net losses and therefore do not borrow from the banks. In low technological regime, the Schumpeterian competition is weak by both motives, the productivity distance between firms is smaller and the price distance too so that firms differentiate less than in the high technological regime. During the long-run growth financial sector is not demanded by firms what contribute for its circumscribed role.

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[12]We have used $\alpha = 0.10$ in all simulations.

## 5. Concluding Remarks

In the last decades, the theories of growth and business cycles have made important advances in explaining the determinants of long-run economic growth and short-run business cycles. The importance of financial mediation for innovation and of innovation for growth is well described, empirically and theoretically, in the literature. The challenge that remains is the integration of growth, business cycles, innovation and finance under a unified framework. However, building such a framework is no trivial task. Aggregate models based on representative agents and analytical solutions might not be the most suitable approach to tackle the task at hand. It is our belief that, a framework based on agent-base computational modelling is more appropriate to analyse complex systems such as the economy. The phenomena of growth and business cycles are emergent properties of the interactions of agents at the micro level. ABM models are capable of capturing all the dynamics involved in the evolution of the economic system, and thus help us to understand how individual decisions give rise to patterns, how these patterns in turn affect individual behaviour, and the dynamics that emerge from this interaction at the macro level.

The model reveals an interesting double role of the financial sector. While, when helping firms cover their operational costs, the financial sector avoids firms' bankruptcies and help them continue producing and innovating, if too many firms are too much indebted, the financial sector reaction of increasing interest rates may create a generalized crisis with a large number of bankruptcies and great reduction on production and on income. Thus, during periods of generalized financial fragility, the financial sector behaves pro-cyclically worsening the financial and economic situation.

Corrigi os dois primeiros paragrafos da conclusão, acredito ser necessário adicionar mais um parágrafo apresentando melhor os resultados do modelo, porém sem descrever o mesmo (isso já foi feito extensivamente na seção anterior). O último parágrafo tb precisa melhorar

The model we have built, despite the results, has some limitations and could be improved to make the details richer and more realistic. First of all the household budget could include an inter-temporal equilibrium mechanism to finance consumption. We have supposed, for the sake of simplicity, that a share of $(1 - \alpha)$ is affected by interest rate without to adopt a mechanism where a household needs to borrow and amortize both the principal and the interest. We reproduce what happens in many aggregated models in the literature. Following the same direction, the household could have a portfolio decision and chose to allocate the income in consumption, capital by providing funds to firms when buying shares directly from the firms or could deposit speculatively the saving in some financial fund controlled by banks. All this together would introduce more complexity and realism in the financial sector side. But we believe that the simpler model is sufficient to deliver the main arguments to tie innovation and Schumpeterian competition to the financial sector in a way that empirical and theoretical literature has suggested. Some important micro-foundations of an integrated theory of growth, business cycles, innovation and finance would have this minimalist model in perspective. If we wish to move forward towards a short run approach, we could include monetary policy by a central bank who could be a source of variation of the interest rate and prices, but at the moment we have focused in the long-run, when monetary policy is neutral. Another front to expand the model is to implement a capital market. We have used a production function based on labour factor only. Capital accumulation could introduce more vectors to rope growth, business cycles innovation and finance. This front means to introduce a second source of growth, by physical expansion rather than productivity. However, this would be another history.

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