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## An Agent-based Model for Secular Stagnation in the USA: Theory and Empirical Evidence

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# An Agent-based Model for Secular Stagnation in the USA: Theory and Empirical Evidence

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**Abstract**

The paper extends the research started with Borsato (2020). I develop an agent-based, stock-flow consistent growth model to analyze the interplay between income distribution, innovation and productivity growth. Results still show that the mounting shrinkage of the labour share impacts negatively upon firm's innovative effort. Additionally, I question the neoclassical belief on the negative interest-elasticity of investments, since decreases in the rate of interest are not associated with increases in capital accumulation. Finally, the panel cointegration analysis based on US manufacturing industries corroborates the theoretical predictions for the period 1958 – 2011.

**JEL Code**: E10, O31, O38, O43, P16.

**Keywords**: Secular Stagnation, Innovation dynamics, Income distribution, Agent-based SFC models, US manufacturing industries, Panel cointegration analysis.

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# Contents

# 1 Introduction

The article extends the framework introduced with Borsato (2020) and deals with the *growth* questions that surround the problem of Secular Stagnation in the United States. The debate on it has strengthened since 2014, when Larry Summers (2014a,b, 2015) recalled that old-fashioned concept to describe the post-2007 US economy. The focus was on structural changes in the economic fundamentals that have caused a significant shift in the natural balance between savings and investments, such that adequate growth, capacity utilization and financial stability would have become hard to achieve. Moreover, as Barry Eichengreen acknowledged, while the term "Secular Stagnation" spread quite fast in the literature, it is like Rorschach test: it means different things to different people (Baldwin and Teulings, 2014; Eichengreen, 2015). Accordingly, I move away from Summers's idea about Secular Stagnation and focus on a particular stylized fact: the long-run tendency of productivity growth to fall since the early Seventies.

The article contribution to the literature is either theoretical or empirical. It is *theoretical* because I develop an agent-based, stock-flow consistent model to analyze the nexus between functional distribution of income and innovative search in moulding productivity and economic growth. Such evolutionary and formal treatment of innovation and distribution is still largely unexplored in the literature on Secular Stagnation. Although the references to and analyses on Secular Stagnation recently intensified, a quantitative and empirical assessment is in fact still scant. A major attempt to provide the topic with a mathematical framework is Eggertsson et al. (2019): Secular Stagnation is there defined as a "persistently low or negative natural rate of interest leading to a chronically binding zero lower bound". The aim of that model is to contextualize Summers (2014a) in the New Keynesian framework. However, their model suffers from some limitations: the treatment of that particular kind of Secular Stagnation leaves the concerns for productivity and innovation dynamics as side results at best; additionally, the absence of substantial heterogeneity among agents and the commitment to a general equilibrium analysis are certainly a weakness.[1]
The implementation of an agent-based setting is, in contrast, particularly suitable to the task since the user knows by construction the micro data generating process and can explore the features of macro-variables as properties emerging out of the evolutionary dynamics (Dosi et al., 2018). More precisely, the agent-based framework is favourable for its focus on *macro-to-micro* and *micro-to-macro* channels that stand behind the surge of Secular Stagnation in the USA. The former route sets crucial phenomena as the social conflict between workers and entrepreneurs occur at macro-economic level, influencing entrepreneurial decisions

[1] Cf. Di Bucchianico (2020) and Pyka and Fagiolo (2005) for specific and general limitations, respectively, detectable in models like Eggertsson et al. (2019)'s.

about innovative search, employment and firm's competitiveness at the micro-economic level. On the contrary, the latter channel results essential in defining the market structure, its evolution over time, and the rise of skewness and persistent heterogeneity in firm's size distribution and productivity differentials. They in particular directly determine aggregate employment and production, and affect the bargaining process that results in the distribution of the social product between wages and profits. More importantly, the second linkage shapes the aggregate dynamics of innovation and productivity which are focal to the specific kind of Secular Stagnation I deal with. The theoretical model helps me show that the increase of the profit share at the expense of the wage share impacts negatively on firm's propensity and ability to innovate. When wages soar, the entrepreneurs will be forced to introduce labour-saving techniques through R&D, so to increase productivity and reduce unit labour costs. As a side result, I observe that the interest rate has non-linear and small effects on either economic growth or innovative activity. The very non-linearity arises because of the contrasting movement the rate of interest spurs on consumption and innovative search.
Secondly, the contribution to the literature is *empirical* because it aims at testing the main theoretical results on a panel of US manufacturing industries from 1958 to 2011. To be precise, I undertake a twofold empirical analysis based on panel cointegration techniques. Firstly, I find empirical evidence of a positive and long-period causal linkage from shipments and wages to R&D spending. The former identify the revenue and the cost components in the precedent theoretical model. I figure out that my series of interest are indeed cointegrated, i.e. there exists a long-run stochastic trend that joins them. I then detect positive and long-lasting evidences, confirming the predictions of my ACE model. The robustness of the results are assessed through the different econometric procedures usually applied to datasets with both large N and large T.
Secondly, I test the existence of a long-run relationship between R&D investments and the effective federal funds rate, on the one hand, and with the bank prime loan rate, on the other hand. I get the interesting result that no long-period well-established linkage exists between innovative effort and the interest rate, whatever measure I adopt for the latter. This lack means that any estimated regression of the former on the latter would provide me with spurious coefficients. Still, that does not conflict with my expectations. So doing, I find at least some plausible explanations for the rise of Secular Stagnation in the United States, among the other rationales often examined: non-technological motives, like lower top marginal tax rates, increased low-skill immigration, rising trade with China and low-cost manufacturing countries or the rise of superstar firms (Autor et al., 2020) are in fact equally admissible.

The paper is therefore organized as follows: Section II reviews the literature; Section III sketches the model; Section IV offers a broad view of the stylized facts the framework matches and related policy experiments; Section V tests some theoretical results empirically; Section VI concludes. The Appendix provides the reader with further information on the theoretical model.

## 2 Relation with the literature

The article draws upon several fields of research. Since it extends the reasoning started with Borsato (2020), this essay broadly shares the literature with it. I therefore refer the reader to the corresponding Section for further knowledge on the theoretical underpinnings of Secular Stagnation in the United States and about the general features characterizing many, if not all, agent-based evolutionary models.

In the present Section I focus on key contributions that strongly influence the theoretical background, on the one hand, and the econometric one, on the other. For what regards to the theoretical setting, this contribution extensively draws on the family of *Schumpeter meeting Keynes* ($K + S$, hereafter) models started with Dosi et al. (2006, 2010), and continued through Dosi et al. (2013, 2016, 2018) and Napoletano et al. (2012). This family investigates the way innovations affect macro-variables through the endogenous generation of supply shocks at the micro- and meso-level of economic activity. An important characteristic is that they link the Schumpeterian tradition of innovation-driven economic growth with the Keynesian theory of demand generation. Definitely, the Schumpeterian engine fuels growth only with Keynesian policies, which do contribute to reduce output volatility and unemployment rates. The general framework described in Dosi et al. (2006, 2010) is furthermore an exercise in *general disequilibrium* analysis, since it goes beyond the standard Walrasian framework that did not mean to address and detail how production, pricing and trade actually arise in real world economies.

The range of topics the $K + S$ framework may address is extended, and Dosi et al. (2013, 2016, 2018) and Napoletano et al. (2012) constitute just a sample of interesting contributions. Dosi et al. (2013) studies the interaction between monetary and fiscal policies, and functional distribution of income, through the development of a banking sector and a monetary authority that sets interest rates and credit lending conditions. The model has got a Minskyan flavour, in that a high volume of production and investments engenders the seed for future recessions. It indeed increases firms' debt with corresponding negative effects on net worth and rising credit risk. This process leads banks in turn to provide loans with tighter conditions or to apply credit rationing. Firms therefore curtail production, creating the premises for a crisis. Dosi et al. (2018) augments the $K + S$ framework to explain the emergence of hysteresis out of the interaction between heterogeneous firms and workers. Hysteresis comes out of coordination externalities and dynamic increasing returns that bear the functioning decentralized economies. This facet goes against the received view of hysteresis as outcome of market imperfections (Blanchard and Summers, 1986). Finally, Napoletano et al. (2012) studies how the interactions between firm's investment behaviour, wage formation and income distribution affect the short- and long-run aggregate dynamics of the economy. Investments can be driven by the stock of liquid assets or by expected demand. However and regardless of the scenario, a balanced distribution of income between wages and profits is focal to the emergence of stable growth paths with low unemployment rates.

A peculiarity of most $K + S$ models is the relevance assumed by fiscal policies: they not only dampen business cycles and reduce unemployment rates, but they are also effective in limiting the occurrence of major crises and fostering long-term growth. This implication is confirmed by Dosi et al. (2016) which aims at comparing short- and long-period effects of Keynesian policies *vis-à-vis* austerity rules for the European Union. They find that rules *à la* Stability and Growth Pact make the economy more volatile, with higher unemployment and prolonged crises. The corresponding depressing effects persist over the long term too.

Wirkierman et al. (2018) and Caiani et al. (2019) are on a similar line of research. The former focuses on the distributional impacts of innovation. The public sector invests directly in R&D and licenses to private firms access to the new technology to produce the final good. Increasing the wage share allows the public sector to drive the process of innovative search toward an outcome in which the distributional impacts of innovation reflect the distribution of contributions to the innovative process. In contrast, the latter investigates the nexus between inequality and growth, assessing the impact of several distributive regimes on innovation dynamics and economic development. The crucial feature is the segmentation of the labour markets in four tiers, according to the role assumed by each worker in the hierarchical organisation of the firm. The distributive regimes concern to the implementation of more, or less, progressive tax schemes and higher, or lower, downward wage rigidity of lower-tier workers. The results are in tune with the literature that emphasizes wage-led growth regimes in a closed economy: more progressive tax systems and measures to sustain low and middle income households help foster economic development and innovation.

For what concerns to the econometrics, I follow and contribute to the literature of time series techniques applied to panel data. These models aim at detecting long-run econometric relationships that typically involve meso- and macro-economic data. Long-period relations are often suggested by economic theory, and researchers are interested in such estimation techniques since they help provide supporting or contrasting evidence (Baltagi, 2008). The development of time series methods and its application to panel data covers a wide range of areas. Such methods include panel unit root tests, panel cointegration tests and the estimation of long-run coefficients. The range of application includes the literature on purchasing power parity (Pedroni, 2001, 2004; Pesaran et al., 1999; Pesaran and Smith, 1995), real wage stationarity (Fleissig and Strauss, 1997), international R&D spillovers (Gutierrez and Gutierrez, 2003; Kao et al., 1999), national innovation systems (Castellacci and Natera, 2013), environmental issues (Hamit-Haggar, 2012) and the relationship between R&D and capital investments (De Jong, 2007).

In particular, Pedroni (2004) tests the strong version of PPP for a panel of twenty countries for post-1973 years. Through a comparison between individual countries and the full panel, Pedroni strongly rejects the validity of strong purchasing power parity as a useful tool to describe post-Bretton Woods period. Fleissig and Strauss (1997) instead question the stationarity of real wage time series for G7 countries from 1960 to 1991, when possible. They find that real wage innovations are temporary, mean-reverting and stationary in all G7 countries but United States. Kao et al. (1999) re-examine Coe and Helpman (1995) analysis on the relevance of international R&D spillovers in supporting economic growth. The sample contains data on domestic and foreign R&D expenditure and TFP for 21 countries plus Israel during 1971 – 1990. They correct the estimation bias which affects Coe and Helpman (1995) results with two different estimators for long-period relationships. Although their results confirm the strong importance of domestic R&D in sustaining TFP growth, they also find the impact of foreign R&D as statistically insignificant.

On national innovation systems, Castellacci and Natera (2013) employs a panel of 87 countries over 1980 – 2007 to investigate the interplay between inputs and outputs of innovative search, on the one hand, and institutional factors such infrastructures and international trade, on the other hand, in shaping the dynamics of national systems of innovation. Despite the favourable evidence for the co-evolution of these factors in the panel as a whole, the specific trajectory followed by distinct national systems changes according to different levels of development. Hamit-Haggar (2012) focuses on Canadian industries over the period 1990 – 2007. The paper aims at studying the long-term causal relationship between greenhouse gas emissions, energy consumption and economic growth. Results provide strong support to the long-run impact of energy consumption on greenhouse gas emissions, while the relation between the latter and economic growth is non-linear. Moreover, estimation outcomes suggest that these variables influence each other in the long-term too, entailing the weakness of any one-way causality assumption. Finally, De Jong (2007) estimates the long-run linkage between capital investments and R&D in a panel of 36 pharmaceutical firms from 1992 to 2004. Estimation results suggest long-run causality exists and runs in both directions. More precisely, physical investments depends on the success of R&D over time since the latter requires additional facilities and equipment; at the same time, R&D is stimulated by capital investments in order to extend the success of current products.

## 3 A growth model for Secular Stagnation

The agent-based model I develop in this essay follows in the footsteps of Borsato (2020). There are few major differences I extensively discuss, but the overall apparatus is the same as before. For this reason, this Section provides a general overview of the model and focuses on which equations actually changed from the previous Part. All the other formal relationships are in the Appendix along with a short description of their meaning.

The model aims at analyzing the relations existing between functional income distribution, innovative search and productivity growth. Moreover, the model is still *complex*, *adaptive* and *structural* as in Tesfatsion (2006): complex for it involves interacting units; adaptive because it experiences environmental changes and structural because it builds on the representation of what agents do. Agents, $N_s$, differ according to their role in the labour market and in their consumption behaviour.[2] For what concerns to the labour market, an agent can be a worker or an entrepreneur. If (s)he is a worker, (s)he offers labour inelastically at the going wage rate and accepts whatever position an entrepreneur opens. For the sake of simplicity, I randomly assign a number of workers to a given firm according to its labour demand. Moreover, hiring workers consists of single-period agreements between agents; this condition means that each agent can move to another firm across periods. I think it is important to underline since the beginning that labour supply is exogenous and unbinding, such that real wages do not clear the market in a Walrasian fashion to ensure full employment; in contrast, the setting admits involuntary unemployment as the rule rather than a particular exception.[3] If the agent is, in contrast, a capitalist, (s)he owns one and (the same) only one firm throughout the simulation. Entrepreneurs take production and investment decisions, they carry out innovative search and may apply for loans if they have not enough retained funds to set up production. In particular, capitalists exert innovative effort to earn a greater amount of profits with a higher market share and to reduce unit labour costs, all through an improved technological apparatus.

The consumption behaviour entails a narrower dissimilarity between social classes than what is in the labour market. Agents, indeed, consume and save regardless of their status and the difference lies in the propensity to consume out of income, which is higher for workers than for businessmen.

[2] *Agent* is an encapsulated set of data and behaviours representing an entity residing in a computationally constructed world (LeBaron and Tesfatsion, 2008).

[3] There is no population growth. Moreover, in a mature capitalist economy as the USA are there is usually a pocket of unemployment, while episodes of labour shortages, if any, are solved through exogenous migration flows.

I again introduce a third type of agent, the bank, which is still consolidated and aggregate. Its activity is the same as before, in that it provides firms with loans and gather household's savings in the form of deposits. Additionally, each agent possesses a *share* of the bank, whose size is proportional to the amount of wealth (s)he has into. This condition gives the agent the right of receiving part of distributed banking profits as dividends. I stress right now that the presence of a passive bank is a limitation but not a major concern. On the one hand, I am not able to study the complex phenomenon of household and corporate debt that greatly substantiates the growth regime the USA has witnessed since the Eighties with a passive agent that does not discriminate between firm's creditworthiness and does not provide households with loans for mortgages. On the other hand, it is true that Secular Stagnation is multi-faceted and many intertwining causes are in place. My scope here is to analyze the specific role played by a macro-economic object, i.e. the social conflict between workers and entrepreneurs, in shaping a micro-economic feature, i.e. the development and adoption of novelties, which in turn addresses and explains the specific macro-economic phenomenon with which I have defined Secular Stagnation in the United States, that is the slowdown of productivity growth. In this way, an active banking system would only add further complexity.

The main novelty with respect to Borsato (2020) consists of the introduction of some mechanisms that allows economic and productivity growth to arise. I figure out two main channels at work and I think a comparison with Borsato (2020) is helpful. The first channel takes place at the macro-economic level and concerns to the social conflict between workers and entrepreneurs, and the respective bargaining process. In Borsato (2020), agents bargained over wage levels as in (1):

$$w_r = \left(w_0 - w_1 \cdot U_{r,t-1}\right) \cdot PR_t \tag{1}$$

in which $w_r$ was the wage rate, $U_{r,t-1}$ the aggregate unemployment rate, and $PR_t$ corrected for inflationary expectations, i.e. the higher the inflationary expectations the higher the wage rate; $w_0$ and $w_1$ were parameters: the former represented all the institutional factors as social norms, customs, market structures and political effects tying the wage rate to a certain path, while the latter did mimic the endogenous evolution of workers bargaining power in relation to unemployment dynamics. I amend (1) assuming the bargaining process occurs over wage growth as in (2):

$$g_{w_r} = w_1 - w_2 \cdot U_{r,t-1} \tag{2}$$

in which $w_1$ plays the same role as $w_0$ in (1), i.e. institutional factors that influence the wage path, while $w_2$ allows for a simple endogenization of the wage rate in that considers the negative influence from the unemployment rate in the labour market. The wage rate grows every period according to the balance of the social conflict as in (3):

$$w_r = w_0 e^{g_{w_r} t} \cdot PR_t \tag{3}$$

in which $w_0$ represents the initial value at the beginning of the analysis.

The second channel takes place within firm's decisions about innovative search and pricing rules. For what regards to innovation, in Borsato (2020) firms invested to earn further profits and to save labour. This rationale was formally written as in (4):

$$i_{rd,j} = \vartheta_0 \cdot c_{av,j} + \vartheta_1 \cdot (\varrho_j - \bar{\varrho}) \tag{4}$$

in which $i_{rd,j}$ was the R&D amount of funds, $c_{av}$ the average revenue from past sales of consumption goods, while $(\varrho_j - \bar{\varrho})$ identified the discrepancy between the actual profit rate $\varrho$ and the normal rate $\bar{\varrho}$; $\vartheta_0$ and $\vartheta_1$ were parameters whereas $j$ indexed a firm. The first element on the right-hand-side was the *revenue* component, whereas the second element envisaged the *cost* component. In the present setting, I model the accumulation rate of R&D, $g_{ird,j}$ as in (5):

$$g_{ird,j} = \vartheta_0 \cdot \bar{g}_{y,j} + \vartheta_1 \cdot \left( \frac{\bar{\varrho}_j - \varrho_j}{\bar{\varrho}_j} \right) \tag{5}$$

Such accumulation rate depends upon a revenue and a cost component as before: the former is $\vartheta_0 \cdot \bar{g}_{y,j}$, in which $\vartheta_0$ is always a parameter while $\bar{g}_{y,j}$ involves a more complex learning process for entrepreneurs than in (4). They indeed no longer consider only the average amount of consumption good sold in the past; they now take into account the amount of investment goods they produced for other firms too. More precisely, they form their expectations over average production growth they did experience in the past. However, they do not consider in their expectations the past as a whole, but they give more importance to recent developments: $\bar{g}_{y,j}$ is therefore computed as a moving average of last periods, to reflect either a gradual learning behaviour or the greater meaning each firm gives to more recent events than what experiences in the very past.
The second element, $\left( \frac{\bar{\varrho}_j - \varrho_j}{\bar{\varrho}_j} \right)$ significantly differs form the corresponding cost component of (4). I here desire to consider two forces at work. Firstly, the normal profit rate is computed as a moving average as $\bar{g}_{y,j}$, to remark the entrepreneurial learning process over the overall profitability innovative efforts entail. In this way, we have that continuously high profit rates affect positively innovative expenditures in the medium-to-long period.[4] However, the actual profit rate may negatively influence innovative effort and the argument runs

[4]This idea is common to the Post-Keynesian literature as in Hein (2012); Lavoie (2014).

as follows: high unemployment and increasing bargaining power of capitalists will reduce the speed with which wages increases, entailing therefore a rise in the rate of profit. Such a reduction will decrease the incentive to adopt labour-saving techniques because the discrepancy and the desire to reach a normal profit rate shrink; the fear for competition seems also attenuated. Capitalists find then a diminished incentive to further mechanize production.[5]

On the pricing rule, firms set prices as mark-up over unit labour costs as I have already written in Borsato (2020). However, the market share affect the evolution of the mark-up and not simply its level:

$$g_{\mu,j} = \nu \cdot \left(\sigma_{m,j} - \bar{\sigma}\right) \tag{6}$$

In this way, capitalists will increase the mark-up through a factor $g_{\mu,j}$ which is set according to the discrepancy between the actual market share and the median share in market $\bar{\sigma}$; $\nu$ is still a coefficient. The rationale is the higher the market share, the higher the willingness and the incentive to raise the mark-up factor, and vice-versa.

The complexity of the model, i.e. the presence of interacting units, envisages what the literature calls *procurement process* (Tesfatsion, 2006). For instance, if we considered the consumption good market, customers would have to decide how much to purchase and at what prices. They must choose a partner among a narrow set of potentials. Once a seller is selected, the customer-supplier relationship involves a long-term commitment. The assumption considers the empirical fact that consumers establish a durable, but not everlasting, relationship of trust and reciprocity to solve problem of asymmetric information.[6] In addition to this, agents interact with each other on five different markets: the (capital) goods market in which firms buy and sell (investment) goods; the (consumption) goods market, in which firms trade goods with households; the labour market, in which capitalists hire and fire workers; the credit market, in which the bank provides firms with loans and the deposit market, in which the same bank gathers households savings in the form of deposits.

To conclude this Section, I briefly sum up the timeline of events, though there is no difference from the model in Borsato (2020). At the dawn of time, I endow firms each with a unit of goods, as their starting level of capital stock. Entrepreneurs compute the target level of capital and, in order to set up production, they may either borrow from the banking system at given interest rates or draw from previous accumulated profits. Once revenues

[5] Dutt (2006); Hicks (1963); Marx (1867) and Hein (2012) provide further details.

[6] "Individuals take decisions according to the limited set of information they have, rational decisions are substituted with reasonable decisions, optimal choices with *satisfying* choices, rational expectations with experience-based *rules of thumb*" (Bassi and Lang, 2016, p. 37). This is tantamount to say that agents have a Simon-type rationality schedule. I concretely apply this assumption with the matching protocol used by Delli Gatti et al. (2005) and Riccetti et al. (2015); more on that in the Appendix.

from sales accrue to the firm, they are distributed as wages and profits. Agents spend part of the received income for consumption purposes and save what remains. The bank collects interest payments from firms and rewards households deposits; additionally, it distributes banking profits to households in proportion to respective wealth. Finally, firms update production plans and perform innovative search: any achievement in productivity will be available at $t + 1$, once the cycle re-started again.

# 4 Validation and policy experiments

## 4.1 Empirical validation: stylized facts

The model is run through 400 periods that roughly correspond to quarters. The baseline scenario is performed along 100 Monte Carlo simulations to wash the variability across runs away. The use of Monte Carlo averages might none the less be problematic according to the model: in a case of quasi-deterministic models it is likely that the evolution of the economy is similar in multiple simulations, whereas more erratic models can exhibit cycles in different periods of the simulation. In the second case, averaging Monte Carlo runs and assessing the results of the simulations based on the mean and confidence intervals can be misleading. The risk is to averaging out interesting phenomena which are only detectable when the dynamics of each simulation is analyzed. A scrupulous study of single simulations reveals however that such case is not a major problem in the present setting, as it was not in Borsato (2020). As common to the majority of ACE models, it does not allow for analytical, closed-form solution. The reason stands in the many non-linearities that distinguish agent decision rules and their pattern of interactions. Agents, firms *in primis*, start from a symmetric condition. For example, firms are endowed with an equal amount of capital goods at the beginning of the simulation. However, the starting symmetry does not prevent heterogeneity comes out in the subsequent stages of development at all, as outcome of agent interactions. For what concerns to parameters and exogenous coefficients, I either borrow from the literature or given reasonable values to match and not to clash with the former. Precisely, key coefficients in key behavioural equations are given stochastic values that vary across agents as in Tab. 13.

How does the model fare with the empirical facts? I carry out an empirical validation to check whether the model is able to replicate at least some of the wide spectrum of micro-economic and macro-economic stylized facts. Tab. 1 reports to the wide spectrum of stylized facts matched by the model.

For what concerns to micro-economic stylized facts, the model matches five well-established

| Stylized facts | Tables - Figures | References |
|---|---|---|
| Micro-economic level (firms) | | |
| Skewness and heavy tailed-ness in firm size distribution | Fig. 1 | Bottazzi and Secchi (2003, 2006) |
| Moments of size distribution are stationary (but not the mean) | Tab. 2, Fig. 2 | Bottazzi and Secchi (2003); Dosi et al. (2010) |
| Heterogeneous productivity and Laplace-distributed growth rates | Fig. 3 | Bartelsman and Doms (2000); Bottazzi and Secchi (2003) |
| Investment heterogeneity and lumpiness | Figs. 4- 5 | Caballero (1999); Doms and Dunne (1998) |
| Persistence of R&D | Tab. 3 | Caballero and Hammour (1991); Harhoff (2000); Le Bas and Scellato (2014) |
| Macro-economic level (aggregate) | | |
| Endogenous and self-sustained growth | Fig. 6 | Caiani et al. (2019); Dosi et al. (2010) |
| Fluctuations at business-cycle level | Fig. 6 | Caiani et al. (2016); Dosi et al. (2010); Stock and Watson (1999) |
| Stock-flow consistency | Fig. 7 | Godley and Lavoie (2006) |
| Output, investment, consumption and unemployment are non-stationary | Tab. 4 | Blanchard and Summers (1986); Hamilton (2020); Nelson and Plosser (1982) |
| Cross-correlation among macro-variables | Tab. 5 | Stock and Watson (1999) |
| Pro-cyclical R&D | Tab. 5 | Wälde and Woitek (2004) |
| Volatility of output, investment, consumption and unemployment | Fig. 9 | Caiani et al. (2016); Dosi et al. (2010); Stock and Watson (1999) |

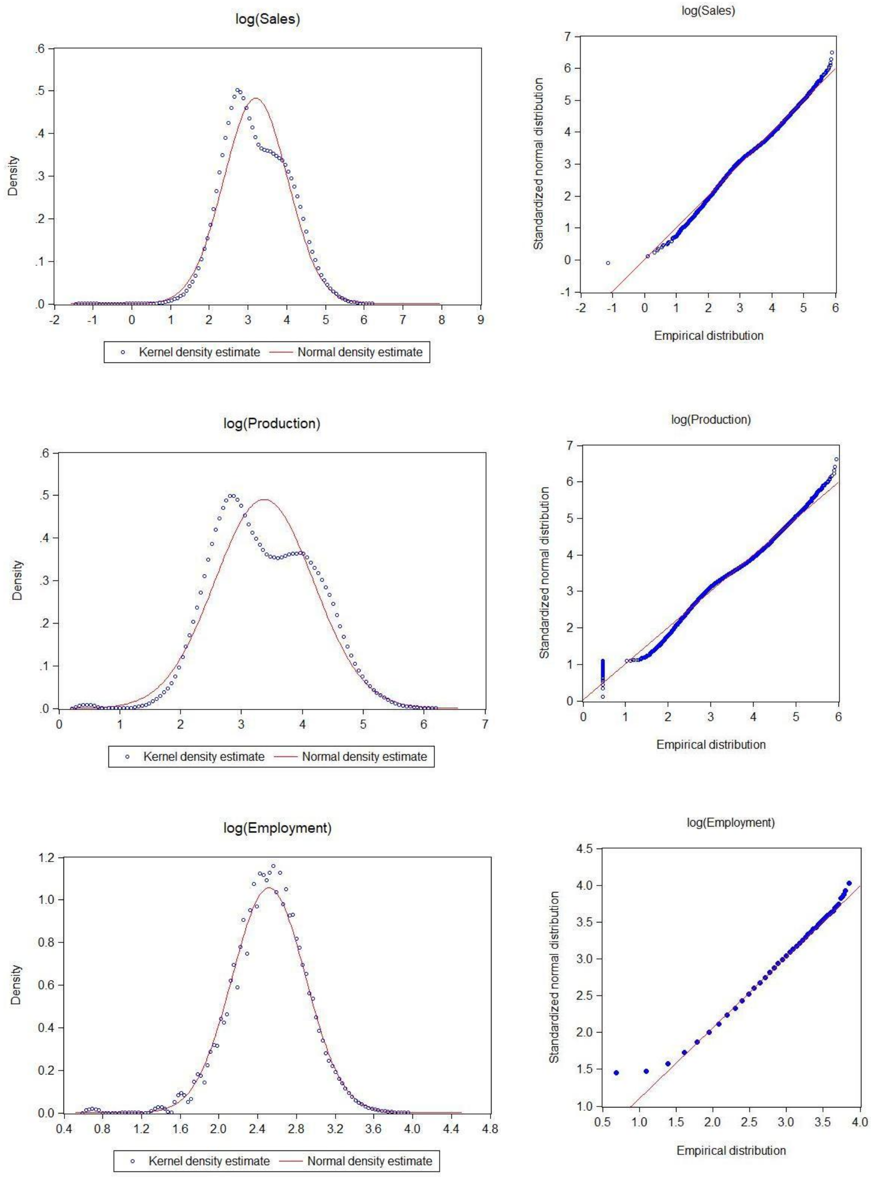
Table 1. Stylized facts matched by the growth model

empirical evidences. First of all, firms size distribution is skewed and heavy tailed as in Bottazzi and Secchi (2003, 2006). I focus on three proxies for firm size, i.e. sales of consumption goods, overall production and number of employees. Fig. 1 shows two different sets of plots: on the left-hand-side, we see the Kernel density for log-transformed data surrounded by a normal distribution; on the right-hand-side, I computed the simple normal probability plot. Simulated data can be well approximated by a log-Gaussian distribution with a sign of bi-modality. It is interesting to make a quick comparison with the model in Borsato (2020). When the model gravitates around a stationary state, the gamma distribution fits perfectly firm's size distribution. The gamma function in this case is either less skewed or less heavy-tailed than the present log-normal distribution. Therefore, the presence of economic growth in the model favours the rise of higher asymmetry and inflates the kurtosis in firm's size distribution. This feature, again, can be obtained through an ACE models only, being standard methodologies not able to outline such an evidence.

Secondly, Tab. 2 and Fig. 2 show that standard deviation, skewness and kurtosis of firms size distribution are stationary processes though they present a very tiny time trend. The first moment, in contrast, exhibits a unit-root process according to the standard ADF test. This result holds for the size proxies of sales and production but not for employment. The non-stationarity of the mean is in tune with Dosi et al. (2010) but not with Bottazzi and Secchi (2003), though in the latter the first moment presents a significant and positive trend.

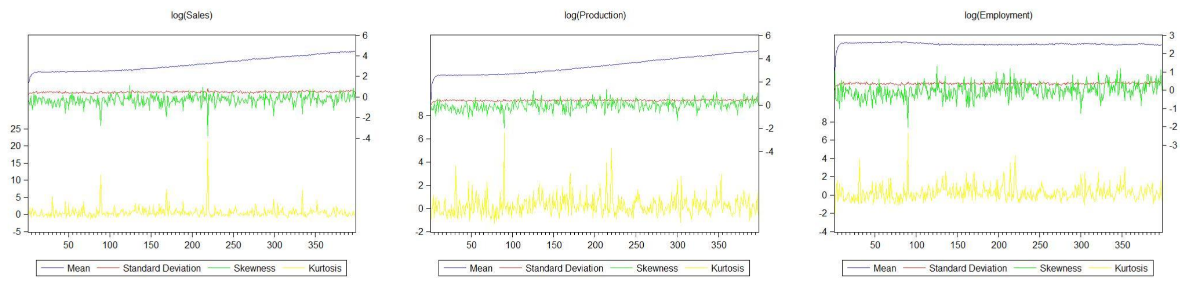
Thirdly, firms are very heterogeneous in terms of productivity and, again, are described by a log-normal distribution.[7] Additionally and still in tune with observed real data, productivity growth rates at firm level are Laplace distributed, so again the distribution is fat-tailed as in Fig. 3. Productivity levels are quite dispersed and differences reflect the differences in the outcomes of technological bets: even if the entrepreneurs bet the same, they

[7] I computed the Jarque-Bera test for my log-transformed variables for each time period: I could not reject the null hypothesis of normality for the strictly vast majority of the cases. Results are not displayed for brevity reasons; they are available upon request. Furthermore, heterogeneity in productivity is more pronounced than in Borsato (2020).




Note: sales refer to shipments of consumption good, while production is about shipments of consumption and investment goods.

Figure 1. Firm size distribution



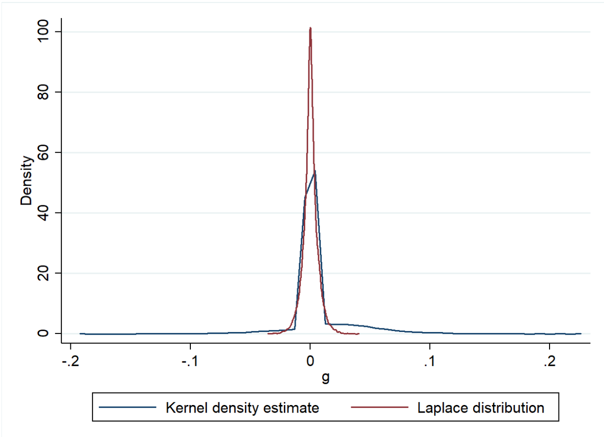

Note: sales refer to shipments of consumption good, while production is about shipments of consumption and investment goods.

Figure 2. Moments of firm size distribution

| | Consumption | | Production | | Employment | |
|---|---|---|---|---|---|---|
| | Trend $\beta$ | ADF test | Trend $\beta$ | ADF test | Trend $\beta$ | ADF test |
| Mean | 0.006 | 0.791 | 0.006 | 0.876 | −0.0001 | −4.109 |
| | (0.000) | (0.994) | (0.000) | (0.995) | (0.014) | (−0.001) |
| Standard deviation | 0.003 | −4.812 | 0.0002 | −5.527 | 0.0001 | −8.429 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Skewness | 0.001 | −18.765 | 0.001 | −10.828 | 0.001 | −10.978 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Kurtosis | $8.10E-05$ | −18.426 | 0.0003 | −17.820 | 0.001 | −17.815 |
| | (0.900) | (0.000) | (0.390) | (0.000) | (0.106) | (0.000) |

Note: p-values in brackets.

Table 2. Moments of (log)size distribution




Note: estimates refer to productivity changes at firm level.

Figure 3. Productivity growth distribution

may not reap the same rewards because of uncertainty (Bartelsman and Doms, 2000).[8]

Fourthly, investment is heterogeneous and *lumpy* as in Figs. 4 and 5: on aggregate, firms experiencing investment spikes co-exist with firms having *near* zero investment. A wide body of literature finds that investments in manufacturing plants is characterized by periods of intense activity interspersed with periods of much lower one (Doms and Dunne, 1998). Moreover, investment spikes correspond to single episodes and are unlikely to wash out on aggregate (Caballero, 1999). This feature rises the question on whether investment is lumpy. Lumpiness means that the same firm switches from periods of high- to period of very low investment expenditures. I plot in Fig. 5 the investment-to-capital ratio pattern of a selected $j$-th firm and I notice the presence of few high-investment periods alternat-

[8] The literature treated firms size distribution and productivity growth rates as if they were independent and separated phenomena. Delli Gatti et al. (2005) explore the link between the two and argue that firms size distribution lays at the root of the Laplace distribution of growth rates. Additionally, many features of business cycle fluctuations, e.g. age of existing firms, amount of profits and "bad debt", follow as a consequence of firms size skewness.

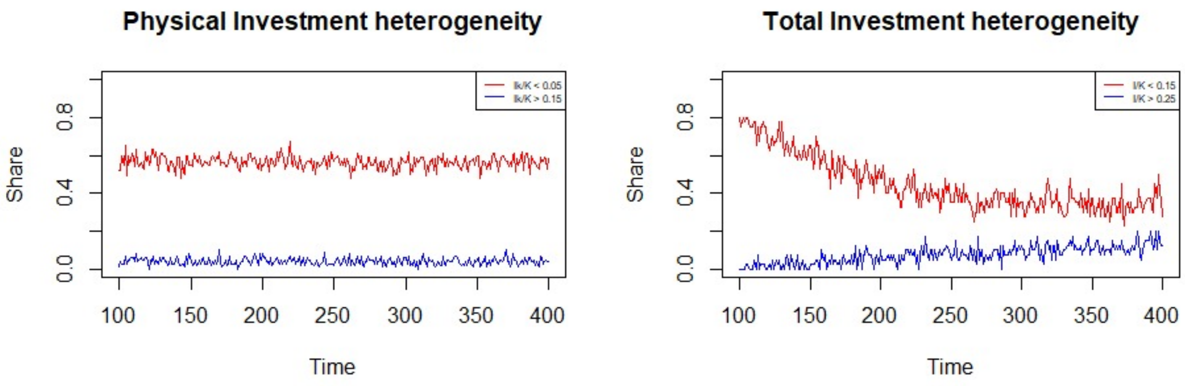
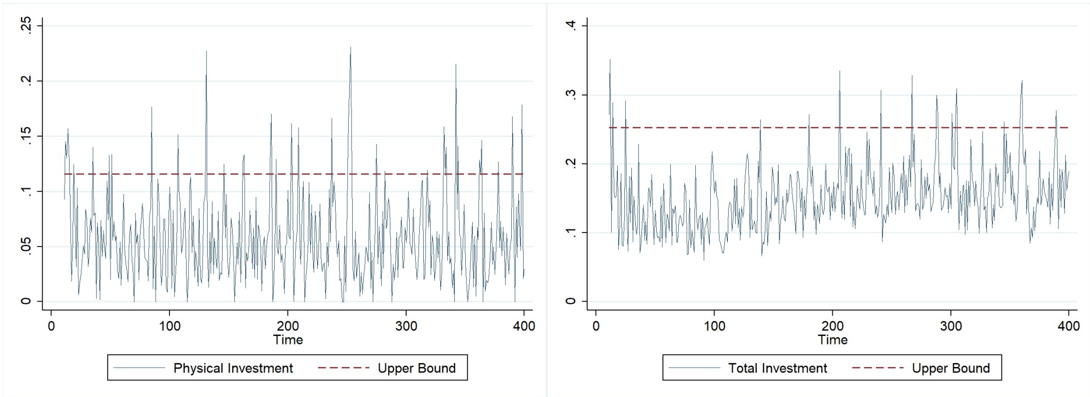



Figure 4. Investment heterogeneity




Note: investment patterns from a selected firm; the upper bound is determined as median value plus one standard deviation.

Figure 5. Investment lumpiness

ing periods of much lower activity.[9] However, we should judge that evidence with care: investment lumpiness in modeling comes out of $(S, s)$ investment functions as in Caballero (1999). Although I did not posit any discontinuous investment schedule, such discontinuities arise out of two main determinants: on the one hand, the matching process between firms and consumers continuously modifies the demand each single firm faces; on the other hand, productivity within the firm may jump to higher values as the result of innovation and imitation, with the important consequences in terms of labour demand. All lead to high-investment periods followed by longer periods of stillness.

Lastly, I want to stress the *persistence* of R&D investments at firm level as in Tab. 3. Firstly highlighted by Caballero and Hammour (1991), the persistence in R&D expenditures reflects the fact that researchers cannot be hired and subsequently fired without a substantial loss of firm-specific know-how that cannot be easily re-allocated to other activi-

[9] The upper bound is computed as the median value across time plus the standard deviation. Similar pictures are discernible for each other firm, whose related graphics are available upon request.

| Panel unit root test | LLC | IPS | ADF-Fisher $\chi^2$ | PP-Fisher $\chi^2$ |
|---|---|---|---|---|
| R&D | 32.422 | 13.322 | 1.229 | 72.702 |
| | (1.000) | (1.000) | (1.000) | (0.706) |

Note: numbers in brackets denote p-values; I adopt the Schwarz-Bayesian criterion to select the optimal lag length. The null hypothesis assumes a common unit root process in the LLC test, while individual unit root process in the others.

Table 3. R&D persistence at firm level

ties (Falk, 2006). The creation of a R&D lab implies a long-run commitment characterized by sunk costs and firms will have a strong tendency to smooth innovative spending over the business cycle more than what they usually do with ordinary physical investments (Mulkay et al., 2001).[10] For simplicity, I detect persistence by testing for unit roots in the panel of simulated firms: I find that all innovative investments are $I(1)$ processes, i.e. they exhibit a high degree of persistence and serial correlation across time. The source of persistence comes out of the watchful process of reflection through which firms do continuously, though slowly, adapt their expectations over future demand.

The model does also replicate a good ensemble of macro-economic stylized facts. First, Fig. 6 shows the general pattern of key variables of interest: output, consumption, investments and related components, labour productivity, deposits, unemployment rate and the wage share. The model generates endogenous and self-sustaining growth path characterized by clear, though tiny, fluctuations at the business-cycle frequency. The unemployment rate converges and gravitates around the reasonable value between 10 and 15 percent, while the wage share converges to 70% in the very long run. The model is stock-flow consistent as in Fig. 7: the adoption of stock-flow norms since the very beginning dampens the arbitrariness of behavioural parameters and the influences from purely stochastic factors.

Second, a recent debate in the literature emphasizes the problem of Harrodian instability in agent-based models (Botte, 2019; Franke, 2019; Russo, 2020). More precisely, although firms strive to reach a normal capacity utilization rate at the micro-economic level, the accelerator effect from their investment schedule does not allow firms to satisfy their objective on aggregate (Botte, 2019).[11] However, the heterogeneity among firms can help solve the puz-

[10] The literature emphasizes two other major causes for the persistence in R&D spending: the "knowledge accumulation" hypothesis, that relates the experience in innovation with learning-by-doing mechanisms, and the "success-breeds-success" hypothesis, that sheds light on the simultaneous influence between innovation and long-lasting profitability. On the several reasons behind R&D persistence, I suggest Harhoff (2000); Manez et al. (2009); Suárez (2014). Le Bas and Scellato (2014) is a synthetic review.

[11] Botte (2019) finds that full-employment ceiling stops the upward Harrodian instability, while an autonomous source of expenditure helps tame the downward instability. Franke (2019) shows the emersion of Harrodian in-

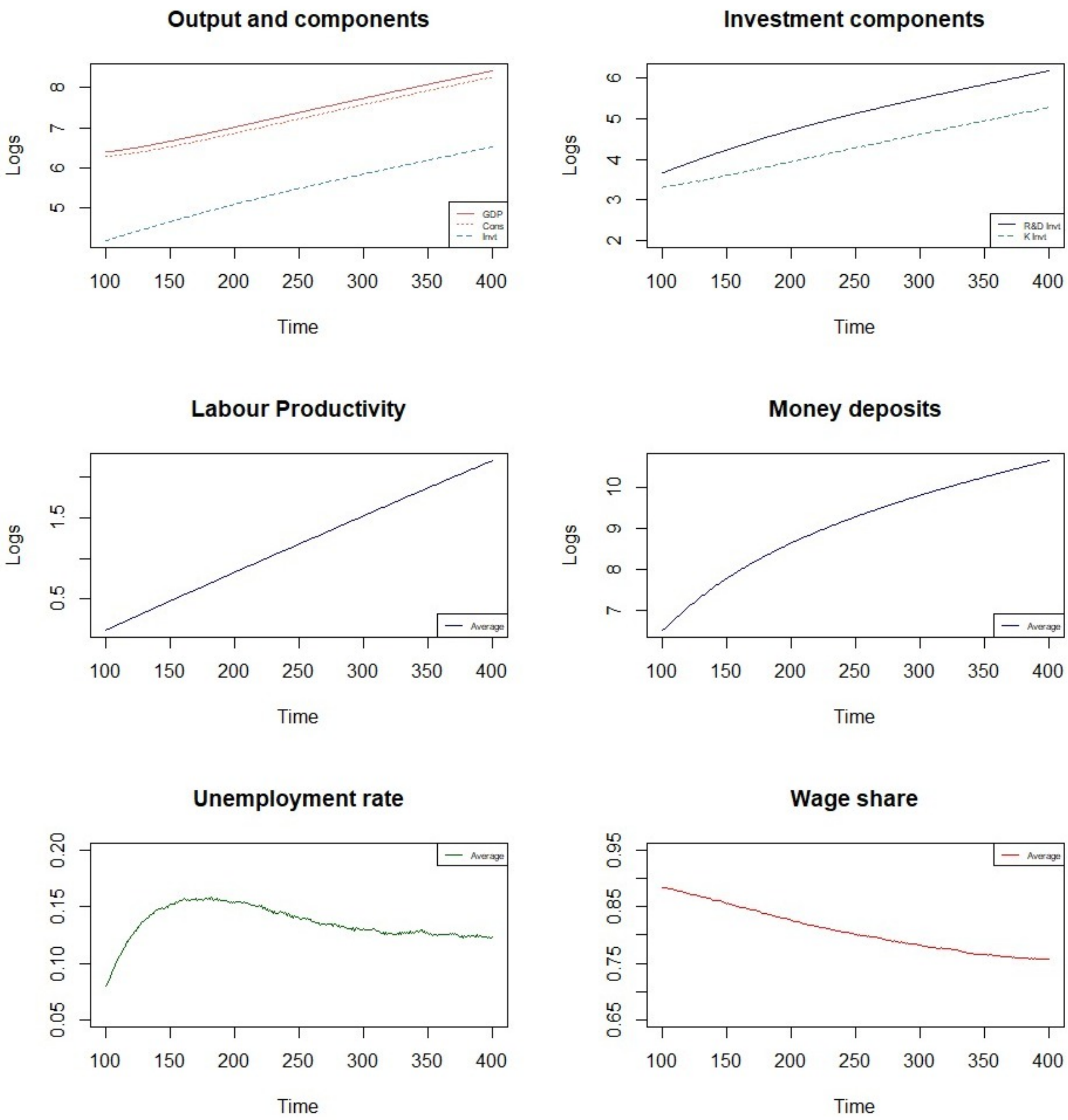



Figure 6. Baseline model: levels in log terms

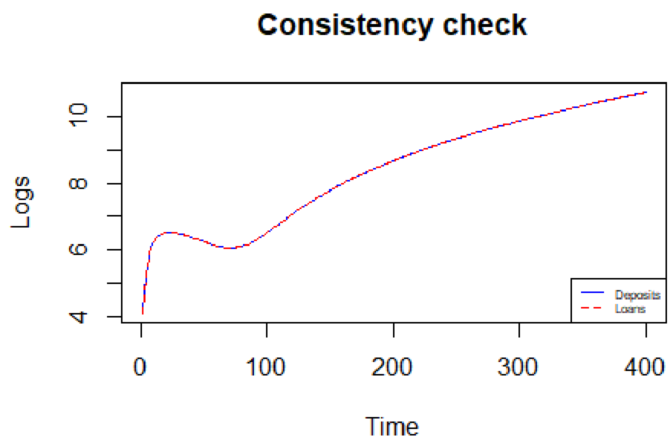


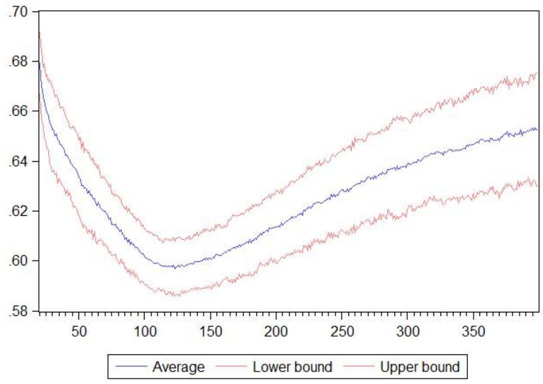

Figure 7. Stock-flow consistency check on selected simulation

zle: Russo (2020) introduces firm-specific shocks in their demand expectations that lead to endogenous business-cycle fluctuations in which capacity utilization does not exhibit explosive dynamics anymore. My setting has several sources that may tame such an instability. First, firms are highly heterogeneous in their investment behaviour and expectations about future demand. In this picture, the matching process between firms and consumers helps lead to a configuration in which optimistic expectations may be counterbalanced by pessimistic ones on aggregate. Secondly, innovative investments are productivity-enhancing: this process has a negative effect on employment rates such that aggregate consumption could fairly decrease, *ceteris paribus*. Fig. 8 shows the long and gradual convergence of capacity utilization toward an average 70 percent. In addition to this, it is worth remarking that business cycles are not a product of stochastic factors but they are endogenous to the model: the matching with consumers and the rise of heterogeneity subject a firm to experience periods of booms and recessions, and to revise its expectations accordingly.

Third, Tab. 4 computes some brief statistics on output, its components and the unemployment rate. The simulated time series present strictly positive average rates of growth and exhibit a unit root. The latter is ascertained through two different unit-root tests so to get robust results. Either the ADF or the KPSS test confirm that all the variables exhibit a unit root, well in tune with the empirical evidence.[12]

stability from a neo-Kaleckian agent-based model in which firms continuously switch between optimistic and pessimistic expectations. Nevertheless, once he adds a third state with *neutral* expectations, the Harrodian instability is tamed if the economy settles into an equilibrium with an equal share of optimists and pessimists that co-exist with a higher share of neutrals.

[12]The unemployment rate follows a fat-tailed distribution whose related figure is not reported for the sake of brevity; it is however available upon request.




Note: bounds are the confidence interval at 95% level; average and bounds are computed across Monte Carlo runs.

Figure 8. Aggregate capacity utilisation rate

| | Output | Investment | Consumption | Unemployment |
|---|---|---|---|---|
| Average | 0.011 | 0.006 | 0.008 | 0.125 |
| ADF test | −0.832 | −0.094 | −1.649 | −1.365 |
| | (0.809) | (0.948) | (0.457) | (0.60) |
| KPSS test | 2.472 | 2.474 | 2.472 | 0.359 |
| | (0.739) | (0.739) | (0.739) | (0.347) |

Note: averages refer to growth rates for output and its components. P-values and critical value at 1% in brackets for the ADF and the KPSS tests, respectively. For what concerns to the unemployment rate, KPSS critical value corresponds to 10% significance level.

Table 4. Output, investment, consumption and unemployment statistics

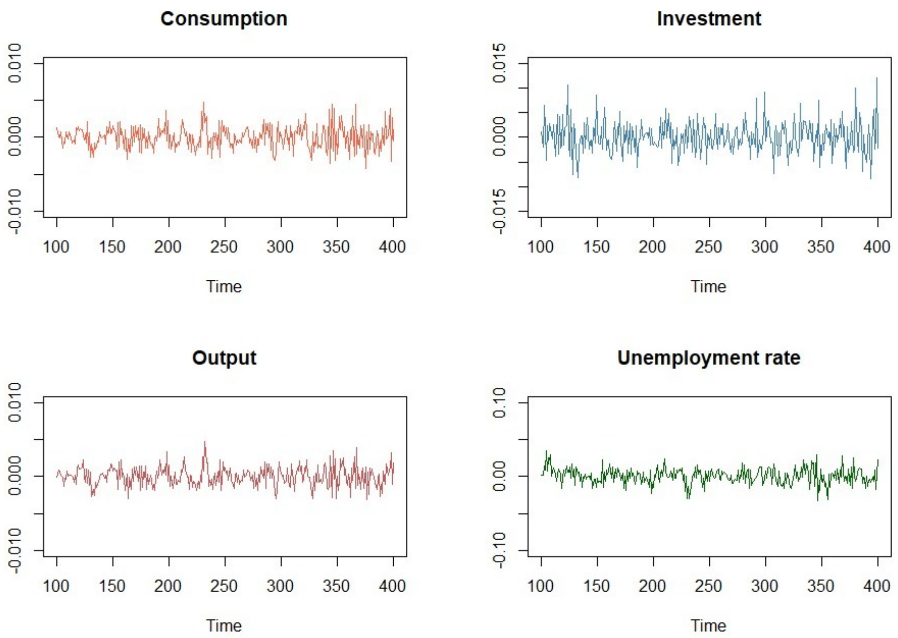



Figure 9. Cyclical components of simulated time series for some aggregate variables

Fourth, Fig. 9 compares the volatility structures of most important variables: consumption, investment, output and the unemployment rate. Still in tune with observed data, unemployment and investments turn out to be more volatile than output and consumption, the latter exhibiting almost the same volatility.[13]

Finally, the model matches the business-cycle properties about correlation structures, as Tab. 5 displays. The table contains cross-correlation coefficients for each aggregate with respect to output. I computed such values considering a wide spectrum of time periods, from $(t-5)$ to $(t+5)$, and associated estimates with a star when significant at 5% level. Investments and labour productivity appear pro-cyclical and leading while consumption tends to synchronize with the business cycle; the unemployment rate is counter-cyclical and lagging. We get from the same table that R&D is pro-cyclical. There is an interesting debate in the literature on the cyclicality of innovative expenditures: the basic argument says that whenever firms experience a sales boom and in the absence of tight credit constraints, they prefer allocating their human and physical assets to current production; hence, longer-term innovative investments should be counter-cyclical, while short-term investments are pro-cyclical (Aghion et al., 2010, 2012; Chiao, 2001; Rafferty and Funk*, 2004). Empirical evidence on that is contrasting and my results are more in line with Dosi et al. (2018), Napoletano et al. (2006) and Wälde and Woitek (2004).

[13]I have separated trends and cyclical components using the Hodrick-Prescott filter; cf. Napoletano et al. (2006) and Fagiolo et al. (2008).

| Series (HP cycle) | Output (HP cycle) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $t-5$ | $t-4$ | $t-3$ | $t-2$ | $t-1$ | $t$ | $t+1$ | $t+2$ | $t+3$ | $t+4$ | $t+5$ |
| Consumption | −0.035 | 0.045 | 0.268* | 0.401* | 0.814* | 0.88* | 0.578* | 0.36* | 0.172* | 0.036 | −0.066 |
| Investment | 0.103 | 0.155* | 0.326* | 0.391* | 0.696* | 0.601* | 0.13* | −0.051 | −0.208* | −0.264* | −0.28* |
| Output | −0.07 | 0.045 | 0.214* | 0.429* | 0.724* | 1* | 0.724* | 0.429* | 0.214* | 0.045 | −0.07 |
| K Investment | 0.108 | 0.166* | 0.323* | 0.405* | 0.685* | 0.632* | 0.287* | 0.007 | −0.232* | −0.323* | −0.354* |
| R&D Investment | 0.077 | 0.11 | 0.273* | 0.3* | 0.593* | 0.447* | −0.15* | −0.139* | −0.131* | −0.121 | −0.11 |
| Productivity | 0.078 | 0.11 | 0.273* | 0.299* | 0.595* | 0.445* | −0.154* | −0.141* | −0.132* | −0.122* | −0.109 |
| Unemployment rate | 0.137* | 0.085 | 0.124* | −0.009 | 0.071 | −0.286* | −0.737* | −0.485* | −0.314* | −0.165* | −0.067 |

Note: star for statistical significance at 5%.

Table 5. Correlation structure

To conclude, I want to point out that the observed features are not simply dependent on a specific parameterization of the model: had parameters been different, its inherent properties, in terms of correlation structures and so on, and the way variables impact on each other would have been the same and not tied to the specific set of parameters (Caiani et al., 2016).

## 4.2 Policy experiments

I have ascertained the ability of the model to replicate some facts observed in real data. The aim of this Section is to ask the model how the economy behaves when I change the value of some parameter of particular interest. I investigate the properties of the model over a different set of scenarios and then I compare the results.
The model has been developed to study the problem of Secular Stagnation in the USA from a demand-side perspective, and precisely I want to study the role played by the functional distribution of income in spurring firm innovative search. Beside that, I want to assess whether the rate of interest does play any role in stimulating the introduction of new technologies.

For what concerns to the role played by income distribution, I must remind from Borsato (2020) that disagreement on its effects still characterizes the literature. On the one hand, there is a widespread belief that distributions of income more favourable to labour, the improvement of social protection systems, the centralization of the collective bargaining structure helps production, capital accumulation and productivity experience higher growth. On the other hand, some might argue that a distribution of the social product more favourable to wage earners dampens firm dynamism. Profit-financed investments would be reduced because of the lower funds aimed at supporting them. Setting a distribution of income more favourable to profit earners helps therefore increase output and employment. I can test which theory prevails through the parameter $w_1$. To remind, it identifies all the institutional, social and political factors that help the growth of the wage rate. The higher the values, the greater the labour bargaining power and so the higher the wage growth. Fig. 10 shows the effect of different scenarios, each performed along 25 Monte Carlo runs. Wages sustain the demand for consumption commodities, on the one hand, and innovative investments on the other. The Schumpeterian entrepreneurs will invest in physical capital to enlarge the stock and not to lose clients. When wages soar, the profit rate drops with respect to the target; the entrepreneur will be forced to introduce labour-saving techniques through the R&D so to rise labour productivity and reduce unit labour costs. The need to counterbalance the increase in the labour cost with the introduction of enhancing-productivity techniques is essential to reduce the unit price or to keep it constant, at least. This need is crucial for her competitive position in the market. Firms find more convenient to adapt production to more labour-saving techniques. However, it is worth remarking that the positive effect prevails over a negative and counterbalancing effect caused by the decrease in the profit rate. Nevertheless the social compromise more favourable to workers leads to technological unemployment. We see from the corresponding panel in Fig. 10 as the higher $w_1$, the higher the unemployment in the economy. The rate with which entrepreneurs introduce technological innovations is greater than output growth: it means that productivity grows more than production and, by definition, employment lessens. This feature is in contrast with what happened in Borsato (2020), when social compromises more favourable to labour clearly let unemployment decrease. Finally, the wage share does not display any clear pattern, and converges to a value between 70% and 80% in the long period: capitalists restore a constant profit share through productivity-enhancing techniques even with social compromises less beneficial to them. Anyhow, the overall result is a better economic performance on aggregate, with higher output growth, higher productivity growth though with slightly higher unemployment.

For what regards to the rate of interest, the economic literature always asked whether, and how, the interest rate stimulates economic activity. The standard neoclassical belief is that a cut in the rate of interest triggers a twofold mechanism. Firstly, the cut stimulates production since capitalists are less burdened by the service of debt. Secondly, the negative elasticity of the investment function is determined by direct and indirect substitution mechanisms: when the interest rate goes down, entrepreneurs tend to increase the capital-labour ratio of their production process to save on the factor become *costlier* – i.e. labour; in addition to this, relative prices of more *capital-intensive* goods decrease, augmenting the previous argument. Therefore, the overall demand for capital increases (Girardi, 2016; Petri, 2004). To sum up, the neoclassical argument expects positive effects either on growth performance and innovation rates after a decline in the interest rate. However and in line with Girardi

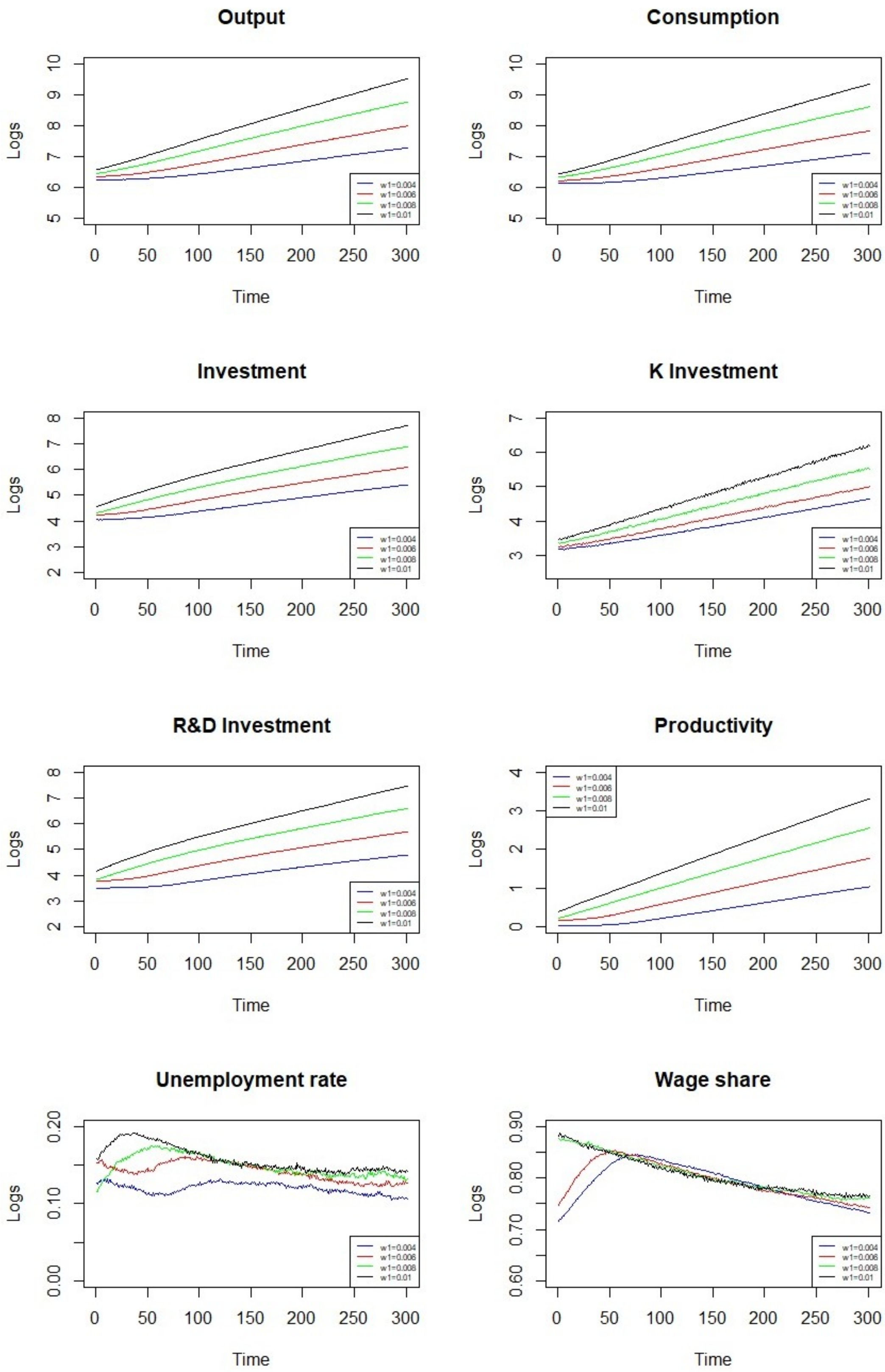



Figure 10. Experiments on income distribution

(2016) and Petri (2004), I did not assume that the rate of interest directly influences investment decisions. Yet, there are several channels through which the interest rate can affect investment and the economic performance. On the one hand, the interest rate directly determines the amount of entrepreneurial profits through the interest payments on past loans; in this way, the interest rate shrinks more, or less, the absolute amount of resources capitalists can re-invest in innovation and capital accumulation; moreover, the consumption out of entrepreneurial profits lessens for the same reason. On the other hand, the higher the rate charged on new loans, the higher the bank profits: a greater amount of the latter then accumulates over households deposits with the corresponding increase of their consumption out of wealth. Through this way, higher interest rates could positively affect the overall performance in the economic system. Figs. 11 and 12 depict the effect of several scenarios with varying interest rates. The interest rate has non-linear and small effect on the level of economic activity. The very non-linearity in the investment pattern arises because of the contrasting movement that the rate of interest spurs on consumption and innovative activity. On the one hand, the entrepreneurs feel less burdened by interest payments so a greater amount of resources accrue to their profits. They are enabled to consume more in absolute terms, and the increase in the latter feeds production and employment. On the other hand, higher profits increase the profit rate and the discrepancy with the target rate shrinks. Moreover, the fear for competition seems attenuated: why should capitalists mechanize production further? Looking at aggregate investment, the non-linearity along monotonic decreases in the rate of interest reflects the different balancing between the increase of aggregate demand on the one side and the lessened need of innovative investment on the other. So we can say that even if the economy seems to perform better in terms of aggregate production and employment, this performance is reached at the expense of technological progress and innovation rates.[14]

Among the several admissible causes of Secular Stagnation in the USA, the experiments help me single out also two important processes that have likely contributed to. The experiments help me to frame and explain Secular Stagnation in the USA as the outcome of two important processes. First, social compromises more favourable to capital owners and the strong dejection of pro-labour reforms as witnessed by the American economy resulted in strictly lower incentive to invest on innovative activities, and the economy experienced a retardation in the growth rates of output and labour productivity. Indeed, innovative investments measured by the amount of R&D expenditure financed by private industries

[14] It is worth reminding that the model does not take into account the negative effect on consumption via household debt, which is a crucial feature of US economy. I have already justified my choice on why I did not deepen such a channel; however, I will focus on it in a future research.

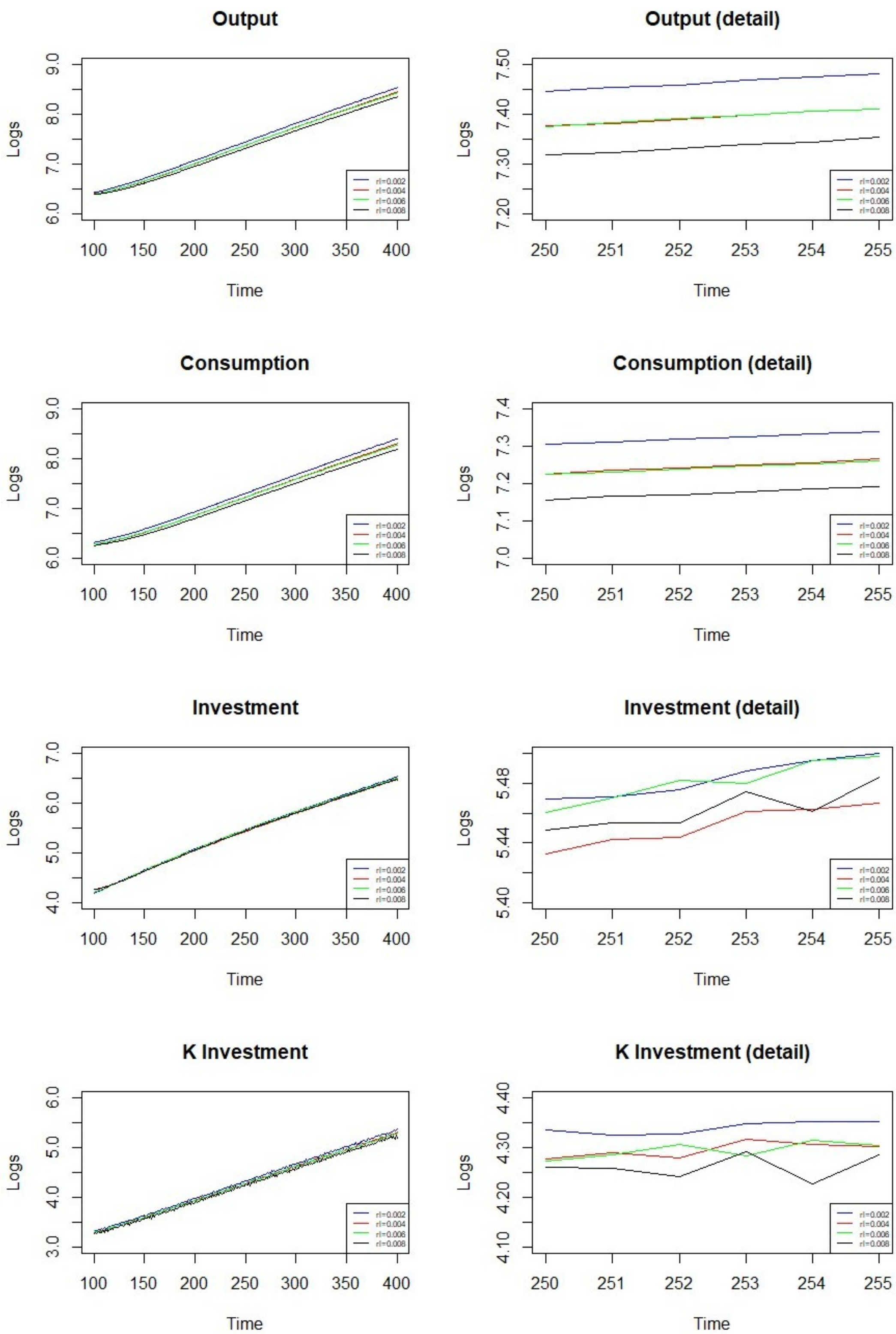



Figure 11. Experiments on the interest rate

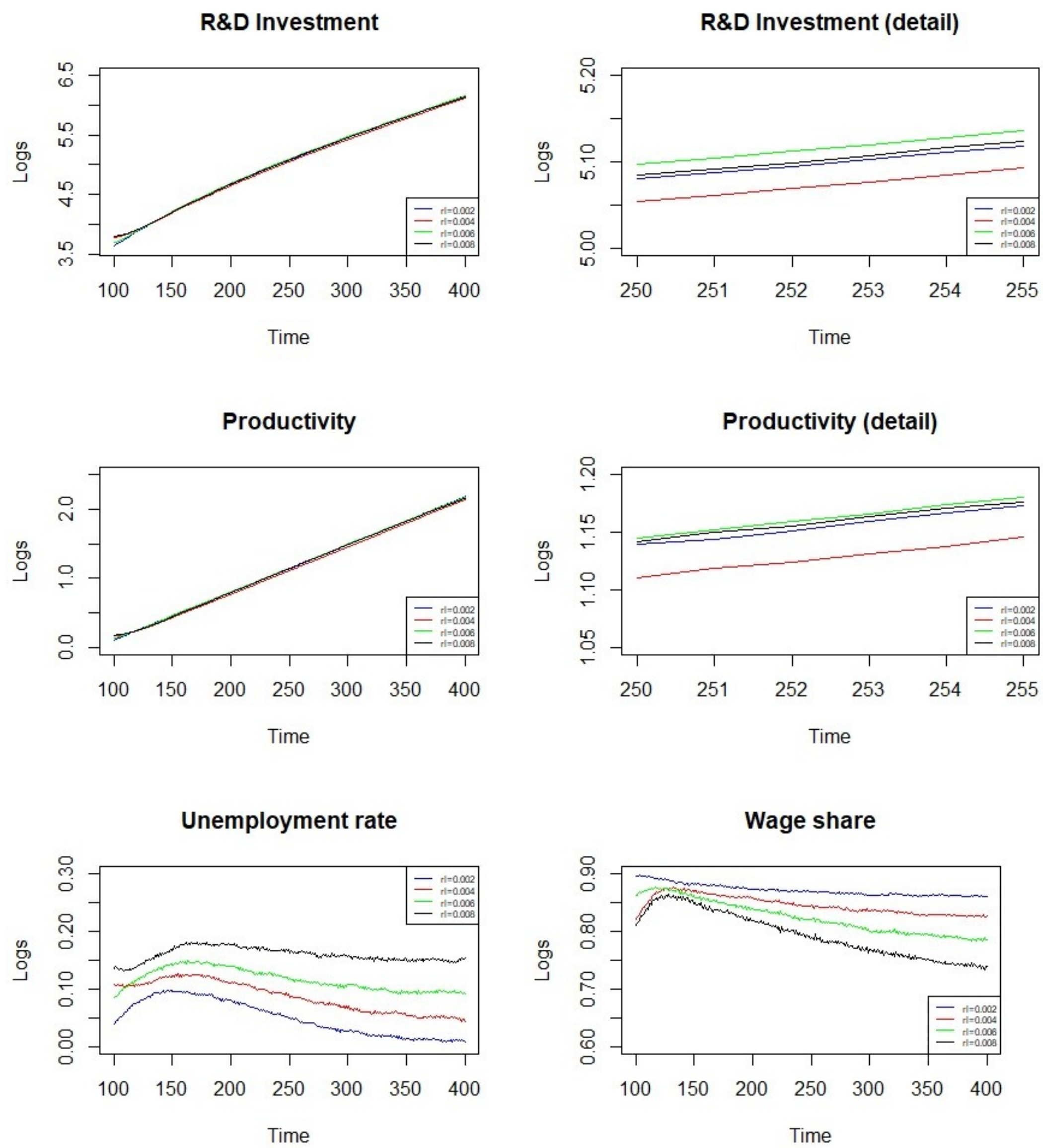



Figure 12. Experiments on the interest rate

has drastically declined in growth terms since the end of the Golden Age of capitalism, as I showed in Borsato (2020).[15] At the same time, lower rates of interest do not seem to be effective in triggering investments in R&D or in physical capital, thus questioning the very effectiveness of monetary policies that keep the interest rate down to very low values. The next Section tries to find empirical evidence of these predictions through a simple econometric analysis on US manufacturing industries.

## 5 Empirical analysis

Once the model is developed and assessed through some experiment it is interesting to find empirical evidence, if any, of theoretical results. It is worth establishing since the beginning that what follows does not aim to provide exhaustive results. I instead want to look at the data and check whether my conclusions on the influence of labour costs and interest rates on the innovative effort may be reasonable. In so doing, I shall split the Section into three parts: I start with a description of the data I am going to use; then I dedicate a subsection to the relationship between innovative search and labour costs and another one for the link between innovation and interest rates. The first empirical check involves a panel cointegration analysis in the line of Kao and Chiang (2001); Kao et al. (1999), Phillips and Moon (2000) and Pedroni (2001, 2004); by contrast, the interplay between innovation and rates of interest is detected through simple descriptive statistics only, because of the lack of any good specification for that.

### 5.1 Data

I focus on a yearly panel dataset of fourteen ISIC-based manufacturing industries that represent the full manufacturing sector in the United States over the period 1958 – 2011. Variables at my disposal concern to R&D expenditure, wages paid to production workers, value of shipments, labour productivity, and two different but close measures for the interest rate: effective federal funds rate and bank prime loan rate. While many statistics are straightforward and *easily* available from international sources, the same does not hold for R&D funds; therefore it is worth spending some words on how to get that measure.
The OECD's Anberd database provides data on R&D activities carried out by the business sector and regardless of the origin of funding. The unit of analysis is disaggregated across a hundred of manufacturing and service industries since 1987. However, the long-run character of the analysis prefers a larger time span; thus I have to cover a period that goes back to the late Fifties at least. The NSF's Survey of Industrial Research and Development –

[15] The same holds for public investment as well, but I reserve to study that issue in future research. Anyway, the interested reader can refer to Deleidi and Mazzucato (2020) and Pallante et al. (2020).

| ISIC Rev.4 | Industry |
|---|---|
| 10 – 12 | Food, beverages and tobacco |
| 13 – 15 | Textiles, wearing apparel, leather and related products |
| 16 | Wood and related products |
| 17 | Paper and related products |
| 18 | Printing and reproduction of recorded media |
| 19 | Coke and refined petroleum products |
| 20 – 21 | Chemical and pharmaceutical products |
| 22 – 23 | Rubber, plastics and other non-metallic products |
| 24 | Basic metals |
| 25 | Fabricated metals |
| 26 – 27 | Electronic and electrical equipment |
| 28 | Machinery equipment |
| 29 – 30 | Transport equipment |
| 31 – 33 | Furniture and miscellaneous manufacturing |

Table 6. List of manufacturing industries

SIRD, now BERD – is the natural candidate. SIRD was the primary source of information on R&D expenditures for profit-seeking, publicly or privately held companies with ten or more employees in the US.[16] Moreover, data are clustered and provided at two digit or industry level, not at firm level. SIRD data allowed to enlarge R&D time series back to 1958. A further problem may be the compatibility between the old US SIC system and the current OECD ISIC classification. I solved that through a scrupulous process of aggregation and check between the different sources. Precisely, I compared the overlapping time span to verify whether SIRD and Anberd gave the same value for a given industry in a given year. Yet, the compatibility need leaves me with a narrow, though comprehensive, cross-section sample, as in Tab. 6.[17]

Wages, values of shipments, and labour productivity data come directly from the NBER Manufacturing Productivity Database developed by Bartelsman and Gray, among the others. Wages are computed as the ratio between production worker wage bill and number of production worker hours; so it is a measure of hourly wage rate. In contrast, value of industry shipments are based on net selling values after discounts and allowances, and they include receipts for contract work and miscellaneous service provided by a given plant to other (Bartelsman and Gray, 1996); labour productivity is computed as real value added over production working hours.[18]

Last two variables are the effective federal funds rate and the bank prime loan rate. The former is the interest rate at which depository institutions trade federal funds, i.e. balances

[16] A company is broadly defined as one or more establishments under common domestic ownership or control.

[17] For any issues or curiosities about SIRD and Anberd surveys, I suggest consulting the related documentation available at https://www.nsf.gov/statistics/srvyberd/prior-descriptions/overview-sird.cfm and http://www.oecd.org/innovation/inno/anberdanalyticalbusinessenterpriseresearchanddevelopmentdatabase.htm, respectively. Moreover, I applied the same procedure for my covariates as well.

[18] Please refer to Bartelsman and Gray (1996) for any kind of issues and curiosities on the NBER database.

| Variable | Label | Obs | Mean | Sd | Min | Max |
|---|---|---|---|---|---|---|
| R&D expenditure | rd | 634 | 5589.518 | 21881.55 | 5.01961 | 318768 |
| Wage rate | w | 756 | 8.55767 | 15.65058 | 0.45845 | 177.2766 |
| Value of shipments | s | 756 | 139852 | 294536.1 | 4103.765 | 3954613 |
| Labour productivity | lp | 488 | 239.3435 | 879.8563 | 2.739767 | 16890.46 |
| Effective federal funds rate | effr | 756 | 0.0553454 | 0.0335722 | 0.00095 | 0.1551 |
| Bank prime loan rate | bplr | 756 | 0.0753165 | 0.0316482 | 0.0325 | 0.1887 |

Note: values are expressed in millions of 2010 dollars. Sources: author's own computations on OECD Anberd database, NSF SIRD survey, FRED St. Louis Fed, NBER Manufacturing Productivity Database.

Table 7. Dataset - descritive statistics

held at FED banks, with each other overnight. The latter is the interest rate that commercial banks charge to their most creditworthy customers. Data and previous definition are from the FRED St. Louis Fed series. Tab. 7 provide some statistics on the variables of interest.[19]

## 5.2 Estimation results: R&D and labour costs.

A clear result from the ACE model above is that wages sustain the demand for consumption commodities, on the one hand, and innovative investments on the other. Entrepreneurs invest in physical capital to enlarge the stock and not to lose clients, and at the same time they will be forced to introduce labour-saving innovations. The need to counterbalance the increase in the labour cost with the introduction of enhancing-productivity techniques is essential to reduce the unit price. This is crucial for their competitive position in the market. I figure the problem of Secular Stagnation in the USA as due even to a progressive shift of income and bargaining power from labour to capital, that resulted in a smaller incentive to undertake innovative effort, among the other plausible rationales. The steady negative pattern of R&D and wage growth or wage share at the industrial level is clearly visible in Figs. 13 and 14 since 1972, i.e. the period I identified as Secular Stagnation; the same holds for industry-level productivity growth.[20]

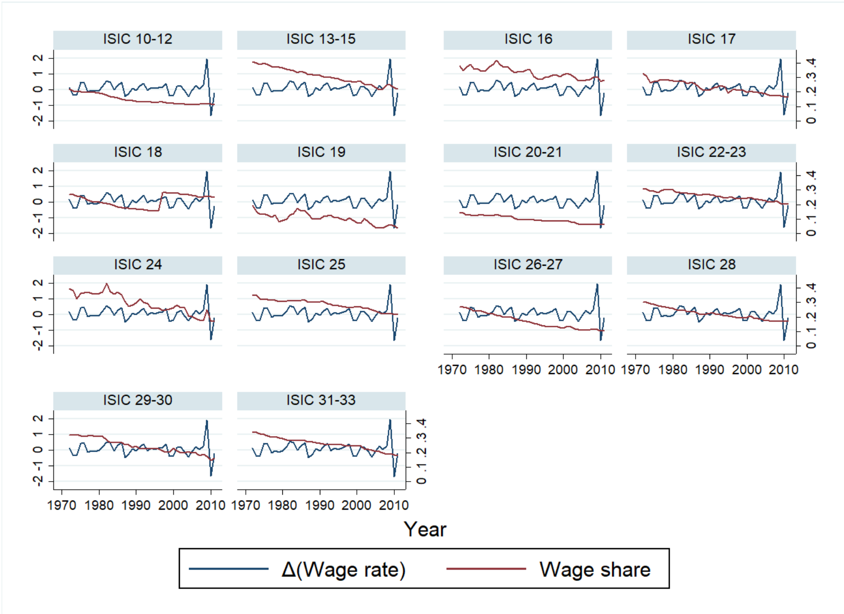
I ascertain we can frame R&D investments at the industrial level as (positive) function of a *cost* component and a *revenue* component:

$$R\&D = f(wages; shipments) \qquad f_w, f_s > 0 \tag{7}$$

in which $f_w$ and $f_s$ represent first derivative with respect to wages and shipments. The aim is to check whether this theoretical long-run relationship holds on the empirical ground.

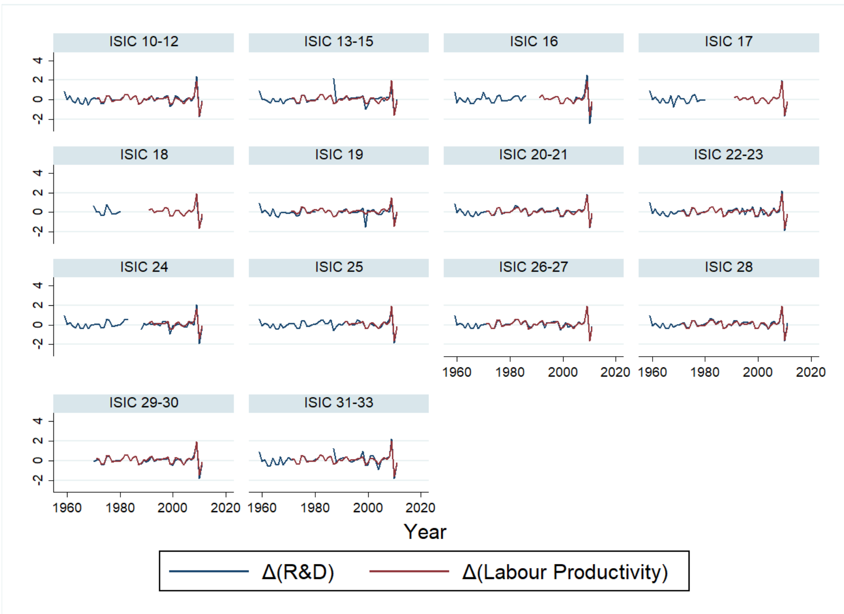
[19] Every variable has been deflated with the GDP implicit price deflator, so to get real terms. I did not deflate interest rates.

[20] The wage share at the industrial level has been computed as wage bill over value added. Moreover, regressions that show steady negative trends are available upon request.




Note: author's own calculations on Anberd and NBER Manufacturing Productivity databases.

Figure 13. Wage rate and wage share across US manufacturing industries, 1972 – 2011




Note: author's own calculations on Anberd, NBER Manufacturing Productivity and NSF SIRD databases.

Figure 14. R&D and labour productivity across US manufacturing industries, 1972 – 2011

Several econometric techniques that rely on panel analysis are available to estimate this relation. In particular, the large temporal dimension at disposal suggests implementing the panel time-series analysis as in Pesaran et al. (1999), Phillips and Moon (2000) and Kao and Chiang (2001) among the others. For the sake of simplicity, I shall assume a long-period relation of the form:

$$\begin{aligned} rd_{it} &= \beta_{0,t} + \beta_{1,t} w_{i,t} + \beta_{2,t} s_{i,t} + \beta_{3,t} d73 w_{i,t} + \\ &+ \beta_{4,t} d07 w_{i,t} + \beta_{5,t} d73 s_{i,t} + \beta_{6,t} d07 s_{i,t} + \mu_i + \varepsilon_{i,t} \end{aligned} \tag{8}$$

where $i = 1, \ldots, N$ is the number of manufacturing industries; $t = 1, \ldots, T$ the number of periods; $rd$ the log of real R&D expenditure; $s$ the log of real value of shipments; $w$ the log of real wage rate; $d73$ and $d07$ are dummies that account for any structural change occurred in 1973 and 2007, respectively. I choose these dates because it is licit to suspect a structural change in the relationship between regressors, due to the oil shock in 1973 and the strong financial crisis in 2007. Moreover, I define Secular Stagnation as a period started precisely between 1972 and 1973. The corresponding interaction terms with the regressors help me detect the presence of any regime switch in the long-run relation with the dependent variable. Finally, $\mu$ is group-specific effect whereas $\varepsilon$ a disturbance term independently distributed across $i$ and $t$.

The econometric procedure involves three steps. Firstly, the long time span rises the problem of unit-roots in the series: I have to test whether innovation investments, wages and shipments are stationary or not. Tab. 8 reports to the results of four specific tests for panel data. The LLC test assumes the presence of a common unit root process in the null hypothesis, while the others are less restrictive and suppose an individual unit root process. All but the LLC test – the latter only with reference to wages – agree on assessing the three variables of interest as nonstationary processes.[21]

Secondly, I have to establish whether any cointegrating relationship exists between them. Cointegration is the condition required for the regression of $y$ on $X$ regressors not to be spurious, i.e. for $\hat{\beta}$ to be consistent for the true value $\beta$. If $y$ and $X$ are $I(1)$, then the disturbance $u$ is $I(0)$ and it does not *swamp* the signal. Through cointegration, $y$ and $X$ have a common stochastic trend which is removed by linear combination (Fuertes, 2016). It is worth emphasizing that panel data spurious regression estimates provide a consistent estimate of the true value of the parameter for $N, T \to \infty$. This characteristic is in sharp contrast with the pure time-series case because panel estimators average out across cross-sections and the

[21] Interestingly, Fleissig and Strauss (1997) applied the LLC test on real wage panel data finding that real wage innovations for the G7 countries, except for the US, are temporary with half-lives generally less than three years.

| | R&D | Wage | Adjusted Wage | Shipments |
|---|---|---|---|---|
| LLC | −0.4415 | −1.5344 | 2.1876 | −1.0927 |
| | (0.3294) | (0.0625) | (0.9856) | (0.1373) |
| IPS | 1.9607 | 0.2908 | 6.1719 | 0.5879 |
| | (0.9750) | (0.6144) | (1.000) | (0.7217) |
| ADF - Fisher $\chi^2$ | 13.7763 | 16.9224 | 5.4676 | 16.4977 |
| | (0.9887) | (0.9501) | (1.000) | (0.9578) |
| PP - Fisher $\chi^2$ | 13.5362 | 16.7784 | 5.0658 | 15.0528 |
| | (0.9902) | (0.9528) | (1.000) | (0.9779) |

Note: panel unit root tests consider individual effects as exogenous variables and I adopt the Schwarz-Bayesian criterion to select the optimal lag length. The null hypothesis assumes a *common* unit root process in the LLC test, while *individual* unit root process in the others.

Table 8. Panel unit root tests

| | Statistic | (Weigthed) Statistic |
|---|---|---|
| Panel v-stat | $3.6834^{***}$ | $1.9165^{**}$ |
| Panel $\varrho$-stat | $-6.6651^{***}$ | $-2.0218^{**}$ |
| Panel PP-stat | $-8.1807^{***}$ | $-3.0154^{***}$ |
| Panel ADF-stat | $-7.7646^{***}$ | $-2.9305^{***}$ |
| Group $\varrho$-stat | $-3.7770^{***}$ | |
| Group PP-stat | $-6.4648^{***}$ | |
| Group ADF-stat | $-7.1560^{***}$ | |

Note: results refer to Pedroni residual cointegration tests where the null hypothesis is of no cointegration; I assume no deterministic trend and I adopt the Schwarz-Bayesian criterion to select the best lag length. Star significance: $^{***}p < 0.01$, $^{**}p < 0.05$ and $^{*}p < 0.1$.

Table 9. Panel cointegration tests

information leads to stronger overall signal. For further details, check Pesaran and Smith (1995) and Baltagi (2008). Tab. 9 shows the results of seven different panel cointegration tests. They all refer to Pedroni (2001, 2004), which proposed multiple tests for the null hypothesis of no cointegration in nonstationary panels that admit for heterogeneity among cross-sectional relationships. The seven statistics I report point out the degree of evidence, of lack thereof, for cointegration in panels among some variables.[22] Through rejecting the null in all the specifications, results seem to agree that variables are cointegrated, so there exists at least a long-period relationship that tie them.

Thirdly, last step is about estimation. I have three estimators at my disposal: the pooled mean group (PMG) estimator, the fully-modified least-squares (FOLS) estimator and the

[22] I have to admit that the relative power of each test and the theoretical intuition behind them are not very straightforward. Still, check Baltagi (2008) for further insights on that problem.

dynamic least-squares (DOLS) estimator. The first was developed by Pesaran et al. (1999) as an intermediate technique between the mean group estimator and the standard fixed-effect one. Developers argue that long-period relationship among variables can be the same across groups, while allowing short-run influences and variances to vary over them. It is a maximum-likelihood type estimator which, however, considers regressors as strictly exogenous. In this setting, yet, I cannot exclude causality runs in both the directions.[23]
The second estimator (FOLS) implements a correction that clears out any problem due to long-run correlation between cointegrating equation and stochastic regressor's innovations; the resulting estimator is asymptotically unbiased and has fully efficient mixed-normal asymptotics. FOLS estimator accounts for endogeneity of the regressors, and correlation and heteroskedasticity of the residuals (Phillips and Moon, 2000). I shall nonetheless emphasize that FOLS estimator is subject to asymptotic bias regardless of how individual effects and deterministic regressors are contained if the regressors are nearly rather than exactly unit root processes (Baltagi, 2008). In this case, the DOLS estimator looks more promising.
Finally, the DOLS estimator involves augmenting the cointegrating regression through adding lags and leads of the regressors first differences, so to wash away asymptotic endogeneity and serial correlation.

Tab. 10 presents the outputs of the regressions based on (8). I carry out two different models for each chosen estimator. *Odd*-number models do not take into consideration possible changes in the long-run relations between dependent variables and regressors, captured by the interaction of dummies and covariates. By contrast, *even*-number models do.[24]

We grab first that the revenue component identified with shipments exerts positive but not always significant effect on the total amount of R&D expenditure. Precisely, a 1% increase in the value of real shipments leads from 0.2 to 0.6% increase in the R&D spending at industrial level, depending on the specification. Additionally, the interaction terms do not turn out to be very relevant, being the exception represented by Model II, in which the parameter associated with $d07s$ clearly shows that the long-run relationship between R&D and shipments has changed and reinforced significantly since 2007. In contrast, for what concerns the cost component, that is hourly wages, results are more uniform: in particular,

[23] Rafferty and Funk* (2004) argue nonetheless that shipments, meant as proxies for demand, can be consider as (weakly) exogenous. The advantage of this demand variable over the other proxies for sales is that the latter are an endogenous mixture of supply and demand forces, while shipments is an exogenous mixture of the current and future demand firms *observe* and consider when deciding R&D budgets. We must handle this belief with caution anyway: that sentence may hold in the short term, but it is well plausible shipments are influenced by successful R&D in the longer run.

[24] Capital stock in the form of equipment and plants is used as control in every regression; both are from the aforementioned NBER database.

| Dependent variable: R&D | PMG | | FOLS | | DOLS | |
|---|---|---|---|---|---|---|
| | Model I | Model II | Model III | Model IV | Model V | Model VI |
| *w* | 0.7195*** | 0.7849*** | 0.8538*** | 0.8123*** | 0.7836*** | 0.3299 |
| | (0.1105) | (0.1238) | (0.1207) | (0.1609) | (0.1424) | (0.2989) |
| *s* | 0.2728*** | 0.1562 | 0.1968 | 0.2446** | 0.2449* | 0.6007** |
| | (0.1084) | (0.1081) | (0.123) | (0.1249) | (0.1422) | (0.2704) |
| *d73w* | | 0.1257 | | −0.0002 | | 0.0993 |
| | | (0.0914) | | (0.1209) | | 0.2393 |
| *d07w* | | −0.2997** | | 0.0893 | | 0.0085 |
| | | (0.01176) | | (0.0907) | | (0.1825) |
| *d73s* | | 0.0062 | | −0.0052 | | 0.0097 |
| | | (0.0049) | | (0.0081) | | (0.0140) |
| *d07s* | | 0.0715** | | 0.0292 | | −0.0178 |
| | | (0.0293) | | (0.0224) | | 0.1098 |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Speed of adj, $\varphi$ | −0.4320*** | 0.4319*** | | | | |
| | (0.0778) | (0.0844) | | | | |
| Log likelihood | 426.2998 | 481.2157 | | | | |
| Observations | 606 | 606 | 622 | 622 | 619 | 622 |
| Periods | 53 | 53 | 53 | 53 | 53 | 53 |
| Cross-sections | 14 | 14 | 14 | 14 | 14 | 14 |

Note: the wage variable is not adjusted by productivity. The careful reader notices the lack of any measure of goodness of fit and the like. I should exercise extreme caution in using these measures because all of them would be computed using the original and not transformed data. For what concerns the choice of leads and lags, I adopted the Schwarz-Bayesian criterion. I control the short-run dynamics with equipment and structures in every regression; additionally I choose the *pooled* panel method for each specification but in Model VI, in which I opted for the *grouped* to avoid cross-section dropouts. Star significance: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 10. Estimation results

a 1% increase in the wage rate leads from 0.7 to 0.8% increase in R&D funds when significantly different from zero.[25]

I have nonetheless to signal a caveat: I did not consider the fact that entrepreneurs may not have any reason to undertake innovative investments if productivity simply increases with wages. I therefore repeat the estimations adjusting wages through productivity; it works as a robustness check too. Results are displayed in Tab. 11 and look quantitatively but not qualitatively different from the above. The expected sign of our coefficients of interest are indeed positive and statistically significant in most cases. Additionally, the interaction terms turn out to be relevant in the majority of the models. Adding interaction terms indeed drastically changes the interpretation of the coefficients: for example $\hat{\beta}_2$ cannot be interpreted as the unique effect of shipments on R&D anymore. The same holds later for labour costs.

Precisely, I can say that whatever specification we observe, the revenue component exerts a positive and significant effect of the dependent variable: a 1% increase on that leads to a 1% increase in R&D spending at the industrial level. In contrast, results are less uniform for what regards to my measure of unit labour costs. The PMG and the DOLS estimations

[25] Even though Pedroni tests found cointegrating relationship, it is always worth checking if the estimated residuals are stationary processes. I applied panel unit root tests for them and I found that they are actually stationary. Results available upon request.

| Dependent variable: R&D | PMG | | FOLS | | DOLS | |
|---|---|---|---|---|---|---|
| | Model I | Model II | Model III | Model IV | Model V | Model VI |
| $w_{adj}$ | 0.2624 | 1.1128*** | 0.5202*** | 0.4709* | 0.3226 | 3.4086* |
| | (0.2264) | (0.3331) | (1.0264) | (0.2802) | (0.2530) | (1.9437) |
| $s$ | 1.0232*** | 0.9458*** | 1.0264*** | 0.9599*** | 1.0244*** | 1.4508*** |
| | (0.0305) | (0.0391) | (0.0350) | (0.0433) | (0.0000) | (0.2138) |
| $d73w_{adj}$ | | 0.0436 | | 0.4807** | | −3.1643 |
| | | (0.2769) | | (0.2291) | | (1.9565) |
| $d07w_{adj}$ | | 0.5039** | | 0.3711*** | | 1.1510* |
| | | (0.2553) | | (0.1452) | | (0.6234) |
| $d73s$ | | 0.0227 | | 0.0582* | | −0.4852** |
| | | (0.0377) | | (0.0321) | | (0.2197) |
| $d07s$ | | 0.0915*** | | 0.0787*** | | 0.1170 |
| | | (0.0331) | | (0.0221) | | (0.0800) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Speed of adj, $\varphi$ | −0.4150*** | −0.4182*** | | | | |
| | (0.0986) | (0.1006) | | | | |
| Log likelihood | 382.8508 | 433.3805 | | | | |
| Observations | 606 | 606 | 622 | 622 | 616 | 622 |
| Periods | 53 | 53 | 53 | 53 | 53 | 53 |
| Cross-sections | 14 | 14 | 14 | 14 | 14 | 14 |

Note: the wage variable is adjusted by productivity. The careful reader notices the lack of any measure of goodness of fit and the like. I should exercise extreme caution in using these measures because all of them would be computed using the original and not transformed data. For what concerns the choice of leads and lags, I adopted the Schwarz-Bayesian criterion. I control the short-run dynamics with equipment and structures in every regression; additionally I choose the *pooled* panel method for each specification but in Model VI, in which I opted for the *grouped* to avoid cross-section dropouts. Star significance: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 11. Estimation results: robustness check

without interaction terms finds no significant relationship between R&D and labour cost, while FOLS estimate does. However, including interaction variables allows me to argue that a 1% increase in the adjusted wage rate is accompanied roughly to a 0.5% increase in R&D funds, at least and when significant. The significance of the coefficients related to the interactive terms shows that the relationship changes through time, especially after 2007.[26]

All in all, I find empirical evidence of prior theoretical results, in that either the *cost* component and the *revenue* component are positively related with expenditures on R&D with respect to the US manufacturing industries since 1958. Results are qualitatively robust to whether we adjust hourly wages with hourly labour productivity. Next step involves the analysis of the relation between R&D and the interest rate, which is going to be set through simple descriptive statistics for the reasons below.

## 5.3 Estimation results: R&D and interest rates.

To investigate the relationship between innovative search and the rate of interest is somehow complicate. I have found more appropriate not to include the interest rate among the

[26] In Model VI I applied the grouped panel method as in Pedroni (2001, 2004). Moreover, the residual diagnostics in each regression shows that residuals are $I(0)$ processes, so I have not the problem of spurious results, though I previously wrote that spurious regressions are not such a huge problem in panel econometrics.

| | R&D - effr | | R&D - bplr | |
|---|---|---|---|---|
| | Statistics | (Weighted) Statistic | Statistics | (Weighted) Statistic |
| Panel v-stat | −1.5239 | −1.6006 | −1.9609 | −1.9631 |
| Panel $\varrho$-stat | 0.2014 | 0.2013 | 1.7243 | 1.7355 |
| Panel PP-stat | −0.6616 | −0.7286 | 1.2104 | 1.1888 |
| Panel ADF-stat | −0.5265 | −0.3897 | 1.5646 | 1.7473 |
| Group $\varrho$-stat | 1.7623 | | 3.0944 | |
| Group PP-stat | 0.0297 | | 2.1218 | |
| Group ADF-stat | 0.1082 | | 2.5287 | |

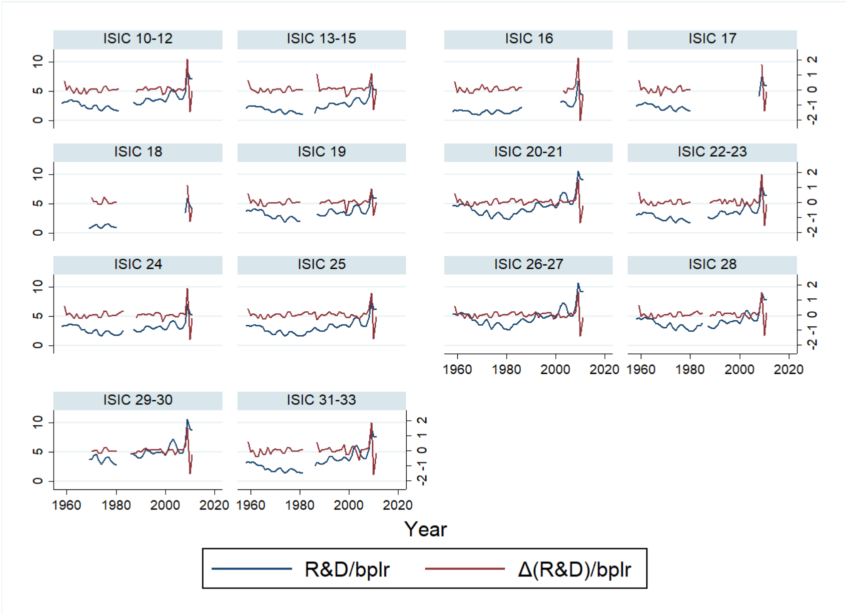
Note: results refer to Pedroni residual cointegration tests where the null hypothesis is of no cointegration; I assume no deterministic trend and I adopt the Schwarz-Bayesian criterion to select the best lag length. Star significance: $^{***}p < 0.01$, $^{**}p < 0.05$ and $^{*}p < 0.1$.

Table 12. R&D and interest rates: Pedroni panel cointegration tests

direct determinant of R&D investments because of the theoretical reasons above. However, as we have discussed, there may still be room for some indirect effects. What I grasp from the previous Section is that the interest rate has a non-linear and small effect upon innovation efforts and on the overall level of economic activity. The very non-linearity in the R&D pattern arises because of the contrasting movement between the revenue and the cost components. On the one hand, capitalists increase the consumption in absolute terms because more profits accrue to their pockets and their need to innovate rises; but on the other hand, they are less afraid of the competitive pressure and reach a normal profit rate more easily, so the necessity to seek for labour-saving techniques looks reduced.

From an empirical point of view, I cannot handle the non-linearity, or to find evidence of it, by simply posing a quadratic or more complex specification in a standard regression model. All of them would be econometric mis-specifications, since I could not detect a well-established or predictable form from previous simulations. Fig. 12 shows indeed that different but close values of the rate of interest determine different schedules in the innovation pattern of the economy, and I am not able to foresee what could be the effect of an increase in the interest rate, as tiny it might be. A straightforward connection between the two probably does not exist. Although I do not suggest or assume any specific relationship between them, I can still perform an econometric cointegration test to see whether any long-run meaningful relation actually exists. Tab. 12 shows the results of Pedroni residual cointegration tests. In particular, I test the existence of a long-run relationship between R&D investment and the funds rate, on the one hand, and with the prime rate, on the other hand. I obtain the interesting result that no long-run linkage exists between innovative search and the interest rate, whatever measure I choose for the latter. It means that any estimated regression of the former on the latter would provide me with spurious coefficients.[27]

[27] I computed also a simple correlation coefficient with the data at disposal and the value was very small, 0.0444, not statistically significant from zero.



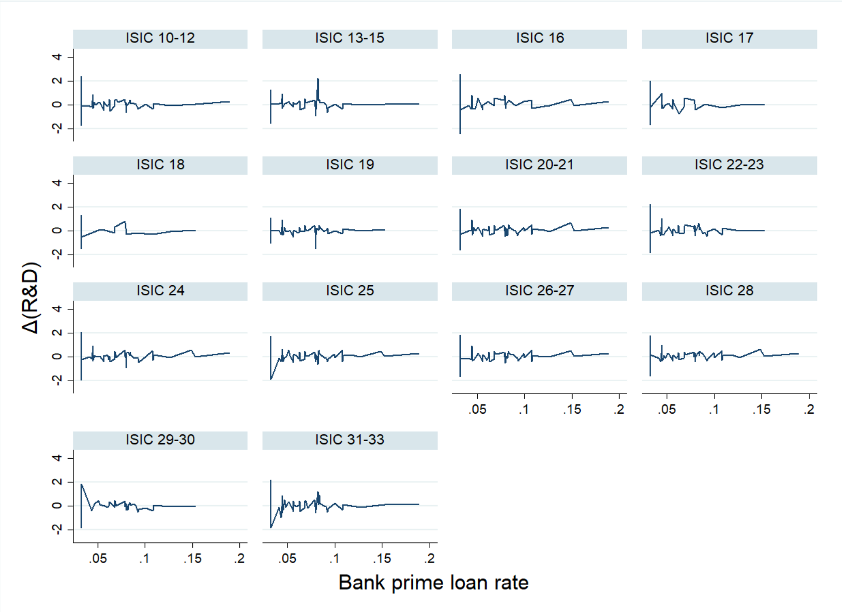

Note: author's own calculations on Anberd, FRED St. Louis and NSF SIRD databases.

Figure 15. Ratio between R&D and bank prime loan rate across US manufacturing industries, 1958 – 2011

Because of that, I have decided to set any econometric and parametric analysis aside, and plot a few descriptive statistics only. Figs. 15 through 18 display different ways of conceiving the time-evolution of R&D and interest rate. The first way is to compute the ratio between the level first – and the growth rate later – of R&D spending and the bank prime loan rate. For what regards to the ratio between R&D in levels and prime rate, it fluctuates around a slightly increasing average trend, while the ratio that considers the R&D growth rates in the numerator swings around a trendless average. These results are clear especially for the cross-sections not affected by missing data.

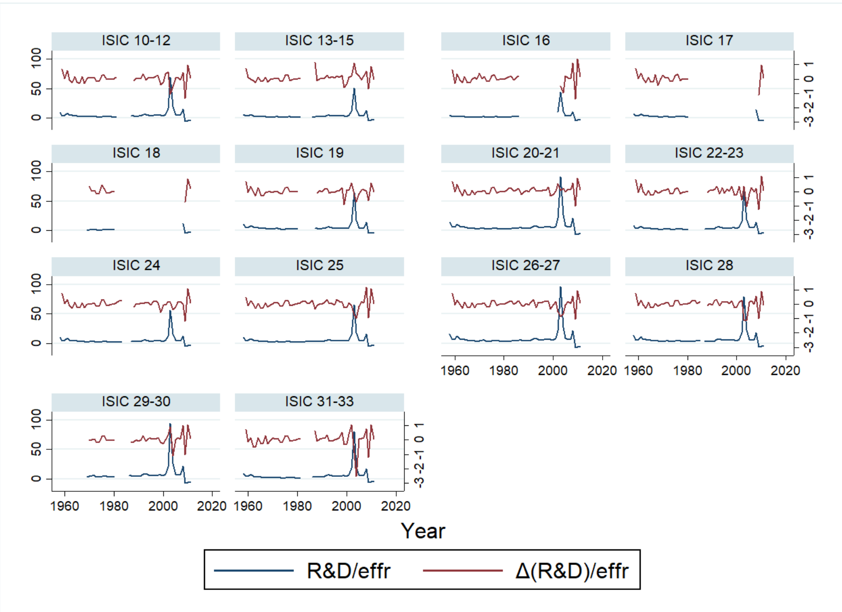
Another way to check the behaviour of these variables is to plot R&D against the prime rate. This method looks closer to the results of the model, in which simple jumps in the rate value prompt change in the innovation pattern. And apparently that is what we see from Fig. 16: different values in the prime rate are associated with different growth rates of R&D. Additionally, they do fluctuate around a flat zero mean. Finally, Figs. 17 and 18 repeat the same exercises using the funds rate in the place of the prime rate; results do not change significantly.

I conclude this Section with a little recap. Among the plausible explanations for Secular Stagnation in the USA, I emphasized the negative effect that the shift of income and bargaining power from wage-earners to profit-earners led to a reduction in the growth rate of R&D investments. The simplest argument ran as follows: a low bargaining power of employees



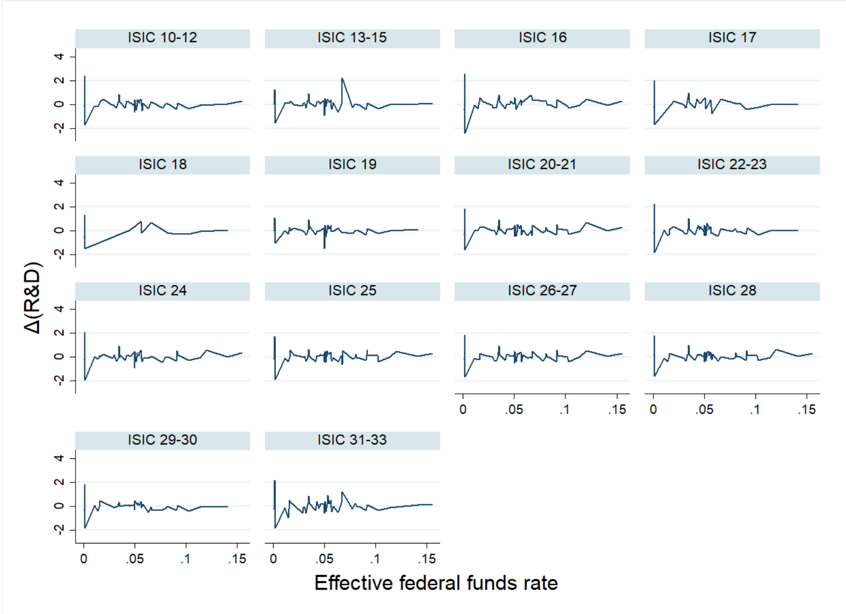

Note: author's own calculations on Anberd, FRED St. Louis and NSF SIRD databases.

Figure 16. R&D against bank prime loan rate across US manufacturing industries, 1958 – 2011




Note: author's own calculations on Anberd, FRED St. Louis and NSF SIRD databases.

Figure 17. Ratio between R&D and effective federal funds rate across US manufacturing industries, 1958 – 2011




Note: author's own calculations on Anberd, FRED St. Louis and NSF SIRD databases.

Figure 18. R&D against effective federal funds rate across US manufacturing industries, 1958 – 2011

and their labour unions, as experienced since the early Seventies, will stop the increase in nominal and real wages, that will finally generate a rising profit share and hence a lower wage share. That will decelerate firms' efforts to improve productivity growth through innovation, because there is no decrease in the profit share to prevent (Hein, 2012). I tested this theoretical implication at the empirical level, focusing on a panel of US manufacturing industries from 1958 to 2011. I adopted different panel cointegration techniques and found that a positive relationship between labour costs and innovation rates generally holds since 1958, with some exception notwithstanding. It contributes to explain the decline in productivity growth, as Secular Stagnation is identified through this work, also by the negative influence exerted by the diminished wage share on firm's innovative search. Moreover, this linkage tends to strengthen since the Seventies, i.e. the period in which I set the theoretical onset of Secular Stagnation, and after the crisis of 2007.

In a second exercise, I detected the existence of any relationship between R&D and interest rates through a basic descriptive line, but I did not find any clear or well-established interplay between them. Moreover, panel cointegration tests do not allow me to reject the null hypothesis of no cointegration in each specification. This result again does not conflict with my theoretical arguments but deserves further research.

## 6 Conclusions

The aim of this article was to extend the research started with Borsato (2020). I studied the problem of Secular Stagnation in the United States, arisen since the early Seventies as a long-run slowdown in the growth rates of productivity, that reached the trough with the Great Recession of 2007. I developed a complex, adaptive and structural ACE growth model in the line of Dosi et al. (2010), Caiani et al. (2016), Tesfatsion (2006), among the others. The ability of the model to satisfy some empirical regularity in terms of firm size distribution, productivity heterogeneity, investment lumpiness, among the other facts, helped me strengthen my theoretical results in terms of policy implications. I investigated the nexus between income distribution and firm's effort to invest on innovative search. I concluded that a low bargaining power of employees and their labour unions, as experienced since the early Seventies, contained the growth of nominal and real wages, that finally generated a rising profit share; firms' effort to improve productivity growth through the introduction of new labour-saving innovations diminished accordingly, since there was no decrease in the capital income share to prevent.

Furthermore, I addressed the neoclassical belief about the negative interest-elasticity of the investment function, since my model showed that decreases in the interest rate on loans were not associated with any surge in capital accumulation. They did instead lead to non-linear and unpredictable effects.

Finally, I carried out a simple empirical analysis for the main theoretical achievements. The focus was on US manufacturing industries from 1958 to 2011. I found empirical evidence confirming my suggestions, with some exception notwithstanding. On the one hand, I found robust empirical evidence of a positive long-period relationship between innovative effort and (unit) labour costs at the industrial level; in addition to this, the positive effect was statistically significant in most specifications. On the other hand, panel cointegration tests led me to claim the lack of any clear and well-established long-run linkage between innovative activity and the rate of interest, the latter measured with the effective federal funds rate or the bank prime loan rate. Obviously, I am not in the position to argue that my explanations for Secular Stagnation in the USA are the only valid rationales. Many other reasons such as the rise of superstar firms or the growing trade with Chinese manufacturing can provide useful information to explain the falling pattern of productivity growth.

In this respect, future research will enlarge the analysis on Secular Stagnation in the USA through the introduction of five issues at least. Firstly, I will shift from functional to personal distribution of income. The introduction of heterogeneous workers in terms of productivity and earnings looks appropriate to explain a further channel through which income inequality may have contributed to the rise of Secular Stagnation in the USA. The framework in

Ciarli et al. (2010, 2019) and Lorentz et al. (2016), in which inequality endogenously arises out of the increase in the number of *tiers* and income classes, seems a promising avenue for my purpose.

Secondly, I would like to remove some of the most restrictive assumptions I accepted thus far, and differentiate between a capital good sector and a consumption good sector. The capital good sector performs R&D and sell new technological vintages in the form of capital goods to consumption good firms. In addition to this, the introduction of inventories and a process of entry-exit dynamics can contribute to analyse the rise of superstar firms as a further symptom of Secular Stagnation.

Thirdly, the question of household and corporate debt: although the very restrictive assumption I made about bank *passive-ness* is not uncommon (Deissenberg et al., 2008), a huge amount of literature pinpoints the role of private debt and banks lending activity in shaping US business fluctuations and economic growth. Secular Stagnation, viewed as a productivity and innovation problem, should take debt dynamics into account.

Fourthly, the introduction of a public agent, i.e. Government, is important to explain discoveries, incentives and adoptions of technological opportunities. Mazzucato (2011) clearly showed the impact of public policies on innovation rates with special reference to the United States.

Finally, the econometric analysis has considered manufacturing industries only. I want to further deepen my study by acquiring firm-level data with respect to either manufacturing or services. Innovation does not occur in manufacturing industries only. A more-in-depth panel analysis may still provide us with further insights on the relationships between firm's innovative effort and income distribution.

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# A Model Recap

This Appendix provides the reader with a quick recap on the equations that constitute the model; there are not major differences with respect to Borsato (2020). For the sake of convenience, I split the equations in seven groups: production firms, labour market, households and consumption, Schumpeterian innovation, banking system, pricing and inflation expectations, and the closure. I assume no inventories with production fully adapting to demand; in addition to this, output components are expressed at constant prices. The letter $j$, if not otherwise specified, refers to the single firm.

## A.1 Production firms

I write production at firm level as:

$$y_j = c_{f,j} + i_{s,j} + i_{rd,j} \tag{9}$$

in which $y_j$ denotes the amount of production which can be split into consumption goods $c_{f,j}$, physical investment $i_{s,j}$ and innovative search $i_{rd,j}$. I adopt the Leontief technology that considers labour and capital as means of production employed in fixed proportions:

$$y_j^P = min\left[\varphi \cdot k_j; a_j \cdot N_s\right] \tag{10}$$

in which $y_j^P$ represents firm's productive capacity, $k$ the capital stock, whereas $\varphi_j$ and $a_j$ are the output-to-capital ratio and the labour productivity within the firm, respectively. A constant proportion $\delta_j$ of the existing equipment depreciates every period and capitalists set aside an amount of funds exactly equal to replace the worn-out capital:

$$da_j = \delta \cdot k_{t-1,j} = af_j \tag{11}$$

in which $da_j$ and $af_j$ define, respectively, the depreciation allowances and the amortization fund. Firms invest either on physical capital or innovative search: the latter has been already described in (5), while the former is a standard accelerator equation, in which the gross expenditure, $i_{k,j}$, encompasses the exogenously-growing animal spirits $i_{0,j}$, the adjustment of capital to the target level $\left(k_j^T - k_j\right)$ and the amortization fund $af_j$: There is no trade-off between different types of investments. We can instead see these investments as complementary: innovation allows for a reduction in unit price while a greater capital stock permits to satisfy a higher turnout. So, if combined, they both raise total earnings.

$$i_{k,j} = i_{0,j} + i_{1,j} \cdot \left(k_j^T - k_j\right) + af_j \tag{12}$$

Entrepreneurial profits, $f_j$, are a residual claim, i.e sales minus the amortization fund, the interest payments on past loans $int_{ld,j}$, and the wage bill at firm level $wb_j$:

$$f_j = y_j - af_j - int_{ld,j} - wb_j \tag{13}$$

Since every firm orders machines to other firms, I define with $i_{d,j}$ in (14) the investment *demand*:

$$i_{d,j} = i_{k,j} + i_{rd,j} \tag{14}$$

However, since what the $j$-th firm demands differs from what is ordered by other firms, I denote with $i_{s,j}$ the amount of investment goods each firm produces for others. For simplicity, it consists of an average amount of physical investments, $\bar{i}_{k,j}$:

$$i_{s,j} = \bar{i}_{k,j} \tag{15}$$

The capital stock $k_j$ is the result of past (depreciated) equipment plus gross investment:

$$k_j = (1-\delta) \cdot k_{t-1,j} + i_{k,j} \tag{16}$$

A firm may borrow from the banking sector to fund its investment expenditure; at the same time, it draws funds from previous accumulated profits. The change in loans demand is then:

$$dl_{d,j} = i_{d,j} - af_j - q \cdot m_{h,t-1,j} \tag{17}$$

in which, $dl_{d,j}$ is the change in loans demand and $q$ is the share of profits re-invested $m_{h,t-1,j}$ by capitalists.

## A.2 Labour market

Firms set labour demand $nd_j$ as the simple ratio between production and effective labour productivity at firm level:

$$nd_j = \frac{y_j}{a_j} \tag{18}$$

The wage bill at firm level, $wb_j$, is the simple product between the wage rate from (3) and the number of employees:

$$wb_j = w_r \cdot nd_j \tag{19}$$

## A.3 Households and consumption

Workers and capitalists consume with propensity $\alpha_{1,i}$ and $\alpha_{2,i}$ out of expected real disposable income, respectively; the propensity to consume out of expected real wealth, $\alpha_{3,i}$, varies only across agents and independently to the status $i$. Disposable income, $ydh_i$, is equal to:

$$ydh_i = \begin{cases} w_r + \sigma_{mh,i} \cdot F_{b,t} + int_{mh,i} & \text{if} \quad i \quad \text{is worker} \\ f_i + \sigma_{mh,i} \cdot F_{b,t} + int_{mh,i} & \text{if} \quad i \quad \text{is capitalist} \end{cases} \tag{20}$$

The flow of income consists of four components: wage rate, entrepreneurial profits, bank profits proportional to agent's wealth $\sigma_{mh,i} \cdot F_{b,t}$, and interest payments on past deposits $int_{mh,i}$. $\sigma_{mh,i}$ represents the share of total wealth belonging to each household; $F_{b,t}$ is the amount to banking profits as in (32). Consumption functions are:

$$c_{inc,i} = \begin{cases} \alpha_0 + \alpha_{1,i} \cdot w_{r,-1} + \alpha_{3,i} \cdot (\sigma_{mh,i} \cdot F_{b,t} + int_{mh,i}) & \text{if} \quad i \quad \text{is worker} \\ \alpha_0 + \alpha_{2,i} \cdot f_{i,-1} + \alpha_{3,i} \cdot (\sigma_{mh,i} \cdot F_{b,t} + int_{mh,i}) & \text{if} \quad i \quad \text{is capitalist} \end{cases} \tag{21}$$

$$c_{wea,i} = \alpha_{3,i} \cdot m_{h,-1,i} \tag{22}$$

$$c_i = c_{inc,i} + c_{wea,i} \tag{23}$$

in which $a_0$ is a autonomous consumption, $c_{inc}$ is the consumption out of income, $c_{wea}$ the consumption out of wealth and $c_i$ the overall consumption. Savings, $dm_{h,i}$, accumulate to the stock of deposits, $m_{h,i}$:

$$dm_{h,i} = ydh_i - c_i \tag{24}$$

$$m_{h,i} = \begin{cases} m_{h,-1,i} + dm_{h,i} & \text{if} \quad i \quad \text{is worker} \\ m_{h,-1,i} + dm_{h,i} - q \cdot m_{h,-1,i} & \text{if} \quad i \quad \text{is capitalist} \end{cases} \tag{25}$$

I have re-adapted the mechanism developed in Riccetti et al. (2015), according to which buyers and sellers meet in the market for commodities and act through a simple procurement process: potential customers observe a subset of prices from a narrow and random bunch of producers, as outcome of imperfect information. The *best* seller will be chosen according to the lowest price. Every period the single customer is given the opportunity to break the relationship with the previous trade partner and switch to another producer with a certain probability. I define the latter as:

$$Prob = \begin{cases} 1 - e^{\chi_1 \cdot \frac{p_{new} - p_{old}}{p_{new}}} & \text{if} \quad p_{new} < p_{old} \\ 0 & \text{otherwise} \end{cases} \tag{26}$$

The simple probability rule tells me the larger the price differential between the former and the new potential supplier, the higher the probability to select the new. The assumption considers the empirical fact that consumers try to establish a durable relation of trust and reciprocity to solve problems of asymmetric and imperfect information (Bowles, 2009).

## A.4 Schumpeterian innovation

Innovation is affected by uncertainty in its *Knightian* form, interpreted as the lack of any quantifiable knowledge about some possible occurrence. Somebody might object the advocacy of Knightian uncertainty as it collides with a model using pseudo-random numbers. Though the pattern generated by this mechanism is based upon randomness, it cannot clearly be *really* random, since any seed produces exactly the same values. Pseudo-random numbers do not replicate Knightian uncertainty. Computers are indeed deterministic machines and cannot produce random values, but can give us series based on algorithms that respect the requirements for randomness. The model is run along many Monte Carlo simulations: attaching a different seed to every single run helps me buffer machine shortcomings. The enterprise has access to several *potential* productivity gains, either through home innovation or from imitation. I identify with $a_{jj}$ the labour productivity in the $j$-th firm as result of its own innovative search, with $a_{ji}$ the productivity of the $j$-th firm as outcome from imitation and with $a_j$ the effective productivity in the $j$-th firm at some point in time; the latter is the maximum between the former. Innovation is a costly process that firms finance part out of new loans and part out of past wealth. To model this process, I select a logistic probability distribution, which is increasing with the cumulative investment on R&D:

$$\lambda_j = \frac{1}{1 + e^{-\varepsilon \Sigma_1^t i_{rd,j}}} \tag{27}$$

The sinusoidal function approaches to 1 as long as the cumulative investment augments over time. To ascertain whether innovation actually occurs, a random number is drawn from a uniform distribution. If the drawn number is lower than $\lambda$, the entrepreneur successes in innovating and productivity will grow accordingly:

$$a_{jj} = a_{t-1,jj} \cdot e^{g_{ird,-1,j}} \tag{28}$$

The imitation process reflects to the above. Entrepreneurs meet a narrow sample of competitors randomly. I exclude free-riders and adopt the law in (27) to state that the probability the capitalist has to imitate is a positive function of her cumulative investments. Once the probability to copy fulfills, the innovative entrepreneur has to evaluate which productivity gain is higher and effective productivity is set accordingly:

$$a_j = max\left[a_{jj}; a_{ji}\right] \tag{29}$$

The innovation process allows for the emergence of heterogeneity across firms, a *path-dependent* heterogeneity that accounts for firm's ability to learn from past experience and competitors. The *learning* ability is the crucial feature of the ACE and it is a key departure from more standard approaches, since the events are driven by agent interactions only, had the initial conditions been specified (Tesfatsion, 2006).

## A.5 Banking system

I suppose the existence of an aggregate big bank that accommodates the demand for loans from the business sector. I further assume any credit constraints away, so the bank provides producers with enough money to cover their investments plans and collects whatever amount of deposits from the public at given interest rates. The equations describing bank behaviour are the following:

$$int_{ld,j} = r_l \cdot \sigma_{ld,j} \cdot L_{d,t-1} \tag{30}$$

$$int_{mh,j} = r_h \cdot \sigma_{mh,j} \cdot M_{h,t-1} \tag{31}$$

$$F_{b,t} = r_l \cdot L_{d,t-1} - r_h \cdot M_{h,t-1} \tag{32}$$

(30) defines firm interest payments on loans as share on total loans: $r_l$ is the interest rate charged on loans whereas $\sigma_{ld}$ is firm's share on aggregate loans; (31) reflects how the bank rewards household deposits as share on total wealth: $r_h$ is the interest rate on deposits while $M_h$ is aggregate wealth. Last equation, (32), computes banking profits, $F_b$, that will be redistributed to households in proportion to their stock of wealth.

## A.6 Pricing and inflation expectations

Firms set prices as a mark-up over unit labour costs:

$$p_j = \left(1 + \mu_j\right) \cdot \frac{w_r}{a_j} \tag{33}$$

in which $p_j$, $\mu_j$, $w_r$ and $a_j$ are, respectively, the unit price, the mark-up, the wage rate and the labour productivity at firm-level. I model the inflation rate as the percentage change in the average price level:

$$\bar{P}_t = \frac{\Sigma_{j=1}^{F}}{F} p_j \tag{34}$$

$$\Pi_t = \frac{\bar{P}_t}{\bar{P}_{t-1}} - 1 \tag{35}$$

Inflation enters the model through its influences on investment and consumption decisions: the idea is that higher inflation decreases the real value of capital goods and the amount of desired consumption. Furthermore, I adopt a *regressive* inflation-expectations process (Sawyer and Passarella, 2019). I denote the expected inflation rate with $\Pi^e$:

$$\Pi^e = \psi_0 + \psi_1 \cdot \left(\Pi^T - \pi_{t-1}\right) + \Pi_{t-1} \tag{36}$$

In (36) $\Pi^T$ is the target inflation rate while $\psi_0$ and $\psi_1$ are parameters. The expected price level $P_t^e$ is then:

$$P_t^e = (1 + \Pi^e) \cdot \bar{P}_{t-1} \tag{37}$$

The final step consists of identifying an inflationary-correcting term to insert into the target-capital and wage functions:

$$PR_t = \frac{P_t^e}{\bar{P}_t} \tag{38}$$

## A.7 Model closure

Last expression concerns to the *redundant equation*, a relationship that equals the stock of loans, $M_s$, with the stock of wealth, $M_h$:

$$M_{h,t} = M_{s,t} \tag{39}$$

Although the model contains no equilibrium condition which makes $M_{h,t}$ and $M_{s,t}$ equal, they must result identical once the model is solved, in accordance to a Walrasian principle (Godley and Lavoie, 2006). Tab. 13 provides information about time span, number of agents, parameter setting and exogenous variables.

| Notation | Description | Value |
|---|---|---|
| $Time$ | Time span | 400 |
| $MC$ | Monte Carlo runs | 100 |
| $F$ | Firms | 40 |
| $N_s$ | Workers-Consumers | 600 |
| $\alpha_0$ | Autonomous consumption | 0.0075 |
| $\alpha_1$ | Worker's marginal propensity to consume out of income | [0.6; 65] |
| $\alpha_2$ | Capitalist's marginal propensity to consume out of income | [0.5; 0.55] |
| $\alpha_3$ | Marginal propensity to consume out of wealth | [0; 0.06] |
| $a_0$ | Labour-productivity initial value | 1 |
| $a_1$ | Coefficient in the productivity equation | 0.75 |
| $\delta$ | Capital depreciation | 0.05 |
| $\varepsilon$ | Parameter in the $\lambda$ function | 0.005 |
| $i_0$ | Autonomous investment at $t = t_0$ | 0.8 |
| $i_1$ | Partial-adjustment coefficient | [0.25; 0.35] |
| $meet$ | Meetings per unit of time | 3 |
| $\mu_0$ | Mark-up at $t = t_0$ | 0.075 |
| $\psi_0$ | Coefficient in the price expectations function | 0 |
| $\psi_1$ | Coefficient in the price expectations function | 0.01 |
| $q$ | Share of wealth re-invested | 0.0216 |
| $r_l$ | Interest rate on loans | 0.0075 |
| $r_h$ | Interest rate on deposits | 0.0025 |
| $\vartheta_1$ | Coefficient in the R&D investment growth equation | [0.01; 0.02] |
| $\vartheta_2$ | Coefficient in the R&D investment growth equation | [0.025; 0.035] |
| $v$ | Coefficient in the mark-up growth equation | 0.85 |
| $w_0$ | Wage rate at $t = t_0$ | 0.5 |
| $w_1$ | Coefficient in the wage growth equation | 0.007 |
| $w_2$ | Coefficient in the wage growth equation | 0.0045 |
| $\chi$ | Consumer's links | 5 |

Note: shaded lines denote variables whose value differs between agents.

Table 13. Parameter setting for the growth model