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Causes and consequences of hysteresis: aggregate demand, productivity, and employment

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Abstract

In this work we develop an agent-based model where hysteresis in major macroeconomic variables (e.g., gross domestic product, productivity, unemployment) emerges out of the decentralized interactions of heterogeneous firms and workers. Building upon the "Schumpeter meeting Keynes" family of models (cf. in particular Dosi et al. (2016b, 2017c)), we specify an endogenous process of accumulation of workers' skills and a state-dependent process of firms entry. Indeed, hysteresis is ubiquitous. However, this is not due to market imperfections, but rather to the very functioning of decentralized economies characterized by coordination externalities and dynamic increasing returns. So, contrary to the insider–outsider hypothesis (Blanchard and Summers, 1986), the model does not support the findings that rigid industrial relations may foster hysteretic behavior in aggregate unemployment. On the contrary, this contribution provides evidence that during severe downturns, and thus declining aggregate demand, phenomena like decreasing investment and innovation rates, skills deterioration, and declining entry dynamics are better candidates to explain long-run unemployment spells and reduced output growth. In that, more rigid labor markets may well dampen hysteretic dynamics by sustaining aggregate demand, thus making the economy more resilient.

JEL classification: C63, E02, E24

1. Introduction

In this work, we explore the extent to which the labor-augmented "Schumpeter meeting Keynes" (K + S) model is able to display the endogenous emergence of hysteresis out of the interaction of heterogeneous firms and workers. The article focuses on both the causes and the consequences of the hysteretical properties of macroeconomic time series, including gross domestic product (GDP), productivity, and unemployment. Further, refining upon Dosi *et al.* (2016b, 2017c), we introduce an endogenous process of accumulation of workers' skills and a state-dependent process of firms entry, studying their hysteretic effects.

As we shall briefly discuss below, there are different notions of hysteresis. Basically, they boil down to three interpretations of the phenomenon (more in Piscitelli *et al.*, 2000, Hallett and Piscitelli, 2002, Amable *et al.*, 2004). The first is formulated in terms of the persistence in the deviations from some equilibrium path; the second is defined as a random-walk dynamics in equilibrium itself; the third, we believe a more genuine one, is in terms of the heterogeneous and nonlinear responses of a system characterized by multiple equilibria or path-dependent trajectories. Even if Piscitelli *et al.* (2000: 59–60) define the former two as *bastard* usages of the notion of hysteresis, they have been so far the most common ones in economics. In this work we shall adopt the third notion which encompasses the phenomena of remanence, super-hysteresis, persistence, nonlinearity, and path dependency. Nonetheless, in an archetypical example, Blanchard and Summers (1986) used the second of the foregoing interpretations in an attempt to explain the structural unemployment in the late 1980s in many European countries, at around 10% and quite far from the predicted 2–3% equilibrium level:

> The recent European experience has led to the development of alternative theories of unemployment embodying the idea that the equilibrium unemployment rate depends on the history of the actual unemployment rate. Such theories may be labelled hysteresis theories after the term in the physical sciences referring to situations where equilibrium is path-dependent (Blanchard and Summers, 1987: 1).

Two alternative hypotheses were proposed by these authors to explain the emergence of hysteresis, a first one resting on the *membership* channel according to which only insider workers are able to exert pressure in the wage setting process, and a second one based on the *duration* channel because the long-term unemployed workers are less relevant in the wage determination process. In the latter case, unemployment duration can (i) induce a process of worker skills deterioration, implying that the long-term unemployed worker experiences a fall in its productivity; and, (ii) trigger search discouragement in unemployed people, less re-employable, and so less prone to search in the labor market.

Together with the supply-side channels emphasized since the 80s, after the current crisis, some acknowledgements have gone to aggregate demand shocks conceived as potential sources of hysteresis. Therefore, the notion of hysteresis has been extended from unemployment to permanent output loss. Blanchard *et al.* (2015) revisit hysteresis as the permanent effect exerted by crises on the the levels of output relative to the pre-crises ones. That work provides evidence of a persistent output gap in 69% of the cases, among 22 countries in the period 1960–2010, where in 47% of them the recession was followed by an increasing output gap, meaning that recessionary periods affected not only the *levels* but also the subsequent *growth rates*, an effect named by Ball (2014) as *super-hysteresis*. In fact, Ball (2014) reports that over 23 countries in the period 2007–2014, most of them have been hit by severe recessions, and some of them, like Greece, faced up to 30% *losses* in potential output.

> [...] in most countries the loss of potential output is almost as large as the shortfall of actual output from its pre-crisis trend. This finding implies that hysteresis effects have been very strong during the Great Recession. Second, in the countries hit hardest by the recession, the growth rate of potential output is significantly lower today than it was before 2008. This growth slowdown means that the level of potential output is likely to fall even farther below its pre-crisis trend in the years to come (Ball, 2014: 2).

The empirical detection of hysteresis, of course, goes together with the analysis of its determinants. Agent-based models are particularly suitable to the task as one knows by construction the micro data-generating process and thus can explore the possible hysteretic features of aggregate variables as emergent properties of the evolutionary dynamics.[1] The model, built upon the "Schumpeter meeting Keynes" family of models (Dosi *et al.*, 2010, Napoletano *et al.*, 2012, Dosi *et al.*, 2013, 2015, 2017a and Dosi *et al.*, 2017c), as we shall see, is able to generically yield hysteresis in the macro variables under scrutiny both *inter-regimes* and *intra-regimes*, i.e., across institutional setups governing the labor markets. Indeed, hysteresis is ubiquitous.

According to our analysis, hysteresis is not due to market imperfections but rather to the very functioning of decentralized economies characterized by coordination externalities and dynamic increasing returns. Contrary to what suggested by, e.g., Blanchard and Summers (1986), our model does not support the hypothesis that rigid industrial relations, via the insider–outsider channel, are the driving source of hysteresis in aggregate unemployment. On

1 See the presentations in Tesfatsion and Judd (2006); LeBaron and Tesfatsion (2008), and Fagiolo and Roventini (2012, 2017) for critical surveys on macro agent-based models (ABMs). For related ABMs which consider a decentralized labor market, see Dawid *et al.* (2014), Russo *et al.* (2016), Caiani *et al.* (2016a), and Caiani *et al.* (2016b), among the others. See also Bassi and Lang (2016) for an agent-based model with investment hysteresis.

the contrary, more in line with Ball *et al.* (2014), our results indicate that during severe downturns and thus declining aggregate demand, phenomena like decreasing investment and innovation rates, skills deterioration, and declining entry dynamics are better candidates to explain long-term unemployment spells and reduced output growth. In such a framework, more rigid labor markets, by supporting aggregate demand, do not foster hysteresis but rather may well dampen it, thus making the economy more resilient.

The article is organized as follows. Section 2 discusses the nature and the sources of hysteresis. In Section 3, we present the model structure. The empirical regularities matched by the K + S model are discussed in Section 4. In Section 5, we study the emergence and the causes of hysteresis. Finally, Section 6 concludes.

2. The nature and determinants of hysteresis

In this section, we provide a brief exploration on the sources and potential channels which might induce hysteretic behaviors in the macroeconomic variables.

2.1 The nature of hysteresis

Hysteresis, a concept adopted from the natural sciences but with similar instances in economics, is a nonlinear mechanism, often implying multiple (alternative) time trajectories and equilibria. In a very broad perspective, a dynamical system can be considered hysteretical when the time trajectories of some or all of its variables do exhibit path dependency, in turn also implying non-ergodicity. The very notion of multiple paths for the development of both socioeconomic and natural complex systems ultimately rests on the idea that history is an essential part of the interpretation of many dynamic phenomena. The property that *history matters* is also intimately related to that of time irreversibility, that is, a situation where it is not possible, even theoretically, to "reverse the arrow of time" and still expects to recover invariant properties of the system under investigation.

Reviewing the literature on complex systems is beyond the scope of this article. Suffice to recall the distinction between nonlinear deterministic systems and stochastic ones, both however displaying forms of path dependency. Concerning the former, instantiations are bifurcation, chaotic, and catastrophe dynamics (see Lorenz, 1993). With respect to the latter, Generalized Polya Urns are a well-known example. Both families of processes are often characterized by the presence of *tipping points* whereby a tip is a threshold point (variable or parameter) which, when reached, might induce irreversible changes on the evolution of the state-space (see Lamberson and Page, 2012 for a detailed discussion in social sciences).

On empirical grounds, in tackling path-dependent phenomena in the social sciences (but also in, e.g., biology), an intrinsic difficulty rests in the fact that frequently only one of the many possible realizations of the system, dependent on its initial state, is empirically observed. In that, how much is history-dependence shaped by initial conditions or conversely how does it relate to irreversible effects of some particular unfolding events (e.g., crises or regime changes)? Related, how do the set of all possible evolutionary paths are shaped and constrained by the structure inherited from the past?[2]

In economics—at least in the dominant theory as distinct from e.g. economic history—the very notion of hysteresis has only been acknowledged with some skepticism and often in the most restrictive interpretations. In the 1980s and 1990s, a stream of literature has faced head-on the challenge of nonlinearity of growth processes and thus the multiplicity of alternative paths and the related hysteretic properties (insightful examples are the contributions in Anderson *et al.*, 1988, Day and Chen, 1993 and Rosser, 2013).[3] However, such a stream of investigation was progressively marginalized, possibly due to its "revolutionary" theoretical implications, particularly in terms of equilibria existence, selection, and the associated welfare theorems. Fundamentally, any form of innovation/knowledge accumulation/learning is associated with dynamic increasing returns and thus nonlinearities (Arrow (1996) witnesses from the General Equilibrium side). Illustrative applications of path-dependent stochastic systems to technology

2 For a more detailed discussion on the relationship between hysteresis and path dependency, see Castaldi and Dosi (2006); Setterfield (2009).

3 The hysteretic properties of economic systems are also studied in the Post Keynesian literature: see Skott (2005); Stockhammer (2011) which identify wage norms and fairness as a potential mechanism to produce an endogenous non-accelerating inflation rate of unemployment (NAIRU).

diffusion are in David (1985), Arthur (1989), and Dosi and Kaniovski (1994). Finally, an analysis of tipping points in hybrid agent-based models (ABMs) have been performed in Gualdi *et al.* (2015).

A usual "safer" path has been that of formalizing the phenomenon based on linear stochastic models with close-to-unit-root auto-regressive processes. In this perspective, Blanchard and Summers (1986) identify hysteresis in the unemployment series whenever the coefficient of persistence ρ in the equation $U_t = \rho U_{t-1} + \alpha t + \epsilon_t + \theta\epsilon_{t-1}$ was estimated to be greater or equal to 1.

Whether a (close to) unit-root process is an adequate sign of hysteresis has been strongly debated. In general, this modeling approach is based on a somewhat naive epistemology—like "Which processes should present unit-roots? The natural rate of unemployment, the inflation target, or the wage setting curve?"—, but without jeopardizing the underlying unique equilibrium assumption. So, for example, Galí (2015) explores, without conclusive results, three alternative sources to a unit-root process of the European unemployment rate, testing whether it lies (i) in the natural rate of unemployment ($U^n_t = U^n_{t-1} + \epsilon_t$), (ii) in the central bank inflation target ($\pi^*_t = \pi^*_{t-1} + \epsilon^*_t$), or (iii) in the insider–outsider hypothesis (à la Blanchard–Summers) via alternative specifications for the New Keynesian Wage Phillips Curve. The obvious dissatisfaction with the unit-root process approach is currently yielding a revival of the detection of nonlinearities in empirical macroeconomics. For example, Beaudry *et al.* (2016), while examining empirical time series like unemployment and working hours, do find evidence of recurrent cyclical patterns, not detectable when estimating auto-regressive linear stochastic models.

However, the critique to the unit-root process approach is deeper and concerns its very underlying theory: as suggested by Piscitelli *et al.* (2000), Hallett and Piscitelli (2002), Amable *et al.* (2004), and Bassi and Lang (2016), *genuine* models of hysteresis should embed a nonlinear structure—or at least do not discard nonlinearity in advance. According to Piscitelli *et al.* (2000), three features characterize hysteretic processes, namely, *nonlinearity*, *selectivity*, and *remanence*. Being this memory process nonlinear, reversing a shock may not drive the system to recover its starting point. Moreover, selectivity means that not all shocks affect the system in the same way in different circumstances. Finally, remanence entails that temporary or non-recurrent shocks may lead to permanent new system states.

Widespread origins of hysteresis in the socioeconomic domain are, first, feedback mechanisms related to *coordination externalities*, and, second, amplification processes stemming from some form of *increasing returns*.[4] In particular, it is frequently associated with (i) positive feedbacks between levels of aggregate activities and innovative search, and (ii) powerful interactions between aggregate demand and diffusion of innovations. Whenever one abandons the unfortunate idea that the macroeconomic system is held up to some mysteriously stable and unique equilibrium path, it could well be, for example, that *negative demand shocks exert persistent effects* because less aggregate demand entails less innovative search, which in turn yields less innovation stemming from technological shocks:

> [During recessionary phases], typically firms also reduce their expenditures in R&D and productivity-enhancing expenditures. The reduction in output reduces opportunities to "learn by doing." Thus, the attempt to pare all unnecessary expenditures may have a concomitant effect on long-run productivity growth. In this view, the loss from a recession may be more than just the large, but temporary, costs of idle and wasted resources: the growth path of the economy may be permanently lowered (Stiglitz, 1994: 122).

Despite the 2008 crisis, many economists continue to believe in some version of the model underlying the Example A in Figure 1: the economy is bound to "spring back," with no permanent loss to its long-run equilibrium rate of growth. The econometric side of this view is the Frisch-like idea of the economy as a "pendulum," responding to exogenous shocks.[5] In this perspective, it seems almost a "miracle" that in the empirical literature one recently finds impulse response functions with multipliers significantly greater than 1. This, we suggest, is a witness of the depth of the current crisis (see Blanchard and Leigh, 2013).

However, a small but significant minority of the profession has been forced by the evidence to accept Case B in Figure 1: recession-induced output losses are permanent because even if the system goes back to the pre-crisis *rate* of growth, then that is associated with an *absolute level gap* growing exponentially over time. Moreover, as discussed in Stiglitz (1994), imperfect capital markets and credit rationing may well exacerbate the effects of recessions, hampering the recovery of the growth rate even further. Beyond that, recurrent negative demand shocks, such as those

4 See Dosi and Virgillito (2018) for a further discussion.

5 For an enticing reconstruction of the discussion between Frisch and Schumpeter on the pendulum metaphor, see Louca (2001).

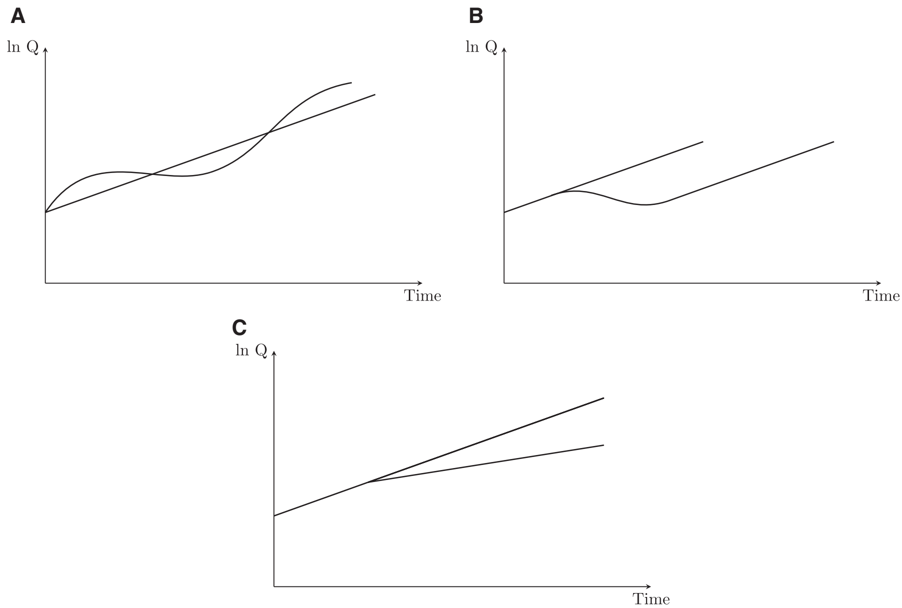

Figure 1. Effects of recessions: (**A**) short-run (no hysteresis), (**B**) long-run (hysteresis), (**C**) permanent/divergent (super-hysteresis). *Source:* (**A** and **B**): Stiglitz, 1994, p. 123.

deriving from austerity or labor market flexibilization policies, might yield *reduced long-term rates of growth*: this is what is shown in Dosi *et al.* (2016a) and Dosi *et al.* (2017c). In the latter scenario, as in the Example C in Figure 1, the pre- and post-crisis growth trajectories diverge, implying a reduced long-run rate of the output growth.

2.2 Innovation, diffusion, and investment

At the empirical level, a *first* microeconomic channel[6] which might induce hysteresis is the lower innovation rate associated with a reduction in the aggregate demand, which turns out in a decline in the productivity growth. Indeed, R&D expenditures are pro-cyclical. Moreover, the diffusion of new technologies and the adoption of capital-embodied, best-practice techniques slow down during crises. Reifschneider *et al.* (2015) document a drop in the yearly rate of growth of R&D expenditure in the United States from 3.6% during the pre-crisis period (1990–2007), on average, to 1.6% after 2007. Not only the propensity to innovate but also the process of adoption and diffusion of innovation is slowed down by the contraction of aggregate demand. Both phenomena have been emphasized long ago by Freeman *et al.* (1982) in their search for the patterns and determinants of long-term fluctuations in growth and employment, and, more recently, theoretically investigated in Dosi *et al.* (2016a, 2017b).

Together with the slower rates of innovation, a process of destruction of the installed productive capacity, due to the lack of sales prospects, seems markedly happening in the post-2008. Indeed, even non-Keynesian commentators have identified the current economic crisis as one stemming from the lack of aggregate demand. As the interest rate reached its zero lower bound without fostering any surge in the investment rate, only accelerator-type investment processes seem able to explain the deteriorating dynamics of the productive capacity. Consistently with the accelerator hypothesis, Kothari *et al.* (2014) report fresh evidence that investments are *ultimately* affected by the dynamics of sales, rather than by the interest rate.

Overall, lower innovation, diffusion and investment rates seem very plausible candidates to explain the current slowdown in productivity. In turn, the fundamental point is that such changes may well bear a long-term impact, that is, *hysteretic effects*, on the future dynamics of productivity, GDP, and employment.

6 The order the channels are presented is *not* relevant in terms of the impact produced by each one upon hysteresis.

2.3 Entry dynamics

The *second* microeconomic channel is the declining entry rate of firms in the market, which has been recently investigated especially in the United States (see Gourio *et al.*, 2016). Entry rates have declined since 2006 by about 27%, a widespread phenomenon across all sectors of the economy. This has been accompanied by steady exit rates and, consequently, also shrinking *net* entry rates. One direct effect of less entry is the reduced creation of new job opportunities. Decker *et al.* (2016) document a long-term pattern in the declining business dynamism which the authors attribute, mainly, to the contracting share of young firms. In a similar vein, Siemer (2014) introduces the hypothesis of a *missing generation* of entrants after the 2008 crisis as a result of the tightening financial constraints, primarily affecting young firms. According to his estimates, the more finance-dependent entrant firms reduced their rates of job creation between 4.8 and 10.5 percentage points relative to the less finance-constrained incumbents. In fact, constrained access to credit may represent an important barrier to entry, together with the usual setup costs, particularly during crises and the associated tight finance availability. Conversely, periods of easy access to debt may induce a higher entry rate (see among others Kerr and Nanda, 2009 and Bertrand *et al.*, 2007).

All in all, both in bad and good times, the entry dynamics seems to be a potentially relevant source of hysteresis.

2.4 Skills deterioration

A *third* microeconomic channel which might trigger hysteresis is the workers' skills deterioration process. Once the economy enters a long recessionary phase, firms tend to fire workers. During severe recessions, like the 2008 crisis, unemployment, which under milder downturns could be in principle temporary and cyclical, turns out to be persistent, implying that many workers experience long unemployment spells. Unemployed workers, of course, stop learning-by-doing, lose contact with the new practices and techniques introduced by firms and gradually deteriorate their existing skills. As the economy recovers and the unemployed are finally hired, their productivity is lower than incumbent workers, reducing the overall productivity.

Looking at the recent figures, Reifschneider *et al.* (2015) document that the share of workers who have been unemployed for more than 26 weeks peaked at 45% in 2011, and it was still about 30% in 2013. On a similar vein, Jaimovich and Siu (2012) analyze the speed of economic recovery during different economic recessions (1970, 1975, 1982, 1991, 2001, 2009) in the United States. Their findings suggest that while in the first three recessions aggregate employment begun to expand within 6 months of the trough of the downturn, during the last three crises employment continued to contract for about 20 months before turning around. Therefore, at the end of 2013 employment had not returned to the pre-crisis level. In turn, Abraham *et al.* (2016) studying the effect of long-term unemployment on employment probability, and earnings find evidence that long unemployment duration is negatively associated with both job-finding rates and earning opportunities, while Ghayad (2013), based on a résumé review study, reports that employers have a strong rejection for long-term unemployed applicants, even in case of equivalent or superior résumé qualification.

Hence, the effects of long unemployment episodes upon skills and job-finding probabilities are yet another important candidate to be a source of macroeconomic hysteresis.

3. The model

We build a general *disequilibrium*, stock-and-flow consistent (see Table B2 in Appendix B), agent-based model, populated by heterogeneous firms and workers who behave according to bounded-rational rules. More specifically, we extend the K + S model (Dosi *et al.*, 2010) with explicitly decentralized interactions among firms and workers in the labor market (Dosi *et al.*, 2016b, 2017c), further adding an endogenous process of workers' skills accumulation and variable number of firms in each market.

The two-sector economy in the model is composed of three populations of heterogeneous agents, F_t^1 capital-good firms, F_t^2 consumption-good firms, L^S consumers/workers, plus a bank and the Government.[7] The basic structure of the model is depicted in Figure 2. Capital-good firms invest in R&D and produce heterogeneous machine-tools whose productivity stochastically evolves over time. Consumption-good firms combine machines bought from

7 The subscript t indicates time dependence. From now on, agent-specific variables are denoted by a subscript i, in case of capital-good firms, j, for consumption-good firms, or ℓ, for workers.

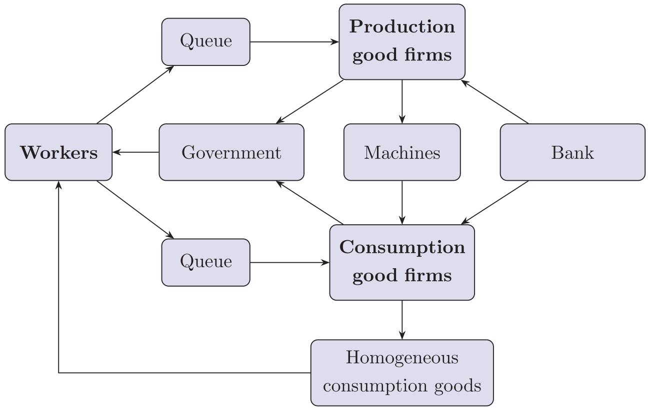

Figure 2. The model structure. Boxes in bold style represent heterogeneous agents' populations.

capital-good firms and labor to produce a homogeneous product for consumers. There is a minimal financial system represented by a single bank that provides credit to firms to finance production and investment plans. Credit is allocated to each firm according to their own demand, which is constrained by their past performance, according to a loan-to-sales cap rule applied by the bank. Conversely, credit supply is completely elastic, adapting to the approved credit demand. Workers submit job applications to a small random subset of firms. Firms hire according to their individual adaptive demand expectations. The government levies taxes on firms' profits, pays unemployment benefits, and sets minimum wages, according to the policy setting, absorbing excess profits and losses from the bank and keeping a relatively balanced budget in the long run.

In the following, we first summarize the functioning of the capital- and the consumption-good sectors of our economy, with a focus on the entry process, and then present the labor market dynamics, detailing the skills accumulation and deterioration mechanisms. Finally, we describe the two alternative policy regime settings under which the model has been explored. In Appendix A, we briefly present the firms', the workers', and the Government behavioral rules (for details, see also Dosi *et al.*, 2010 and Dosi *et al.*, 2017c). The model main variables, its configuration, and the parameter setup are presented in Appendix B.

3.1 The capital- and consumption-good sectors

The capital-good industry is the locus where innovation is endogenously generated in the model. Capital-good firms develop new machine-embodied techniques or imitate the ones of their competitors to produce and sell more productive and cheaper machinery. On demand, they supply machine-tools to consumption-good firms, producing with labor as the only input.[8] The capital-good market is characterized by imperfect information and Schumpeterian competition driven by technological innovation. Machine-tool firms signal the price and productivity of their machines to the current customers as well to a subset of potential new ones, and invest a fraction of past revenues in R&D aimed at searching for new machines or copy existing ones. Prices are set using a fixed markup over (labor) costs of production.

Consumption-good firms produce a homogeneous good employing capital (composed by different "vintages" of machines) and labor under constant returns to scale. Desired production is determined according to adaptive (myopic) demand expectations. Given the actual inventories, if the current capital stock is not sufficient to produce the desired output, firms order new machines to expand their installed capacity, paying in advance—drawing on their retained past profits or, up to some limit, on bank credit. Moreover, they replace old machines according to a payback period rule. As new machines embed state-of-the-art technologies, the labor productivity of consumption-good firms increases over time according to the mix of vintages of machines in their capital stocks. Consumption-good firms

8 The latter is a usual simplifying assumption which avoids the introduction of a multilevel capital-goods sector and keeps the innovation process more transparent (see, on a three-sector economy, Seppecher *et al.*, 2017).

choose in every period their capital-good supplier comparing the price and the productivity of the machines they are aware of. Firms then fix their prices applying a variable markup rule on their production costs, trying to balance profit margins and market shares. More specifically, firms increase their markup and price whenever their market share is expanding and vice versa. Imperfect information is also the normal state of the consumption-good market, so consumers do not instantaneously switch to the most competitive (cheaper) producer. Market shares evolve according to a (quasi) replicator dynamics: more competitive firms expand, while firms with relatively lower competitiveness levels shrink, or exit the market.[9]

3.2 The entry and exit processes

We expanded the earlier K + S model to account for a variable number of firms in both the consumption- and the capital-good sectors (F_t^1, F_t^2). In this new version, entry and exit are now independent processes. As before, firms leave the market whenever their market shares get close to 0 or their net assets turn negative (bankruptcy). However, we now define the number of entrants by means of the random variables b_t^1 and b_t^2:

$$b_t^z = F_{t-1}^z[(1-o)MA_t^z + o\pi_t^z] \qquad \text{(lower bounded to 0)}, \tag{1}$$

where $z \in \{1,2\}$ denotes the sector (capital- or consumption-good, respectively), F_{t-1}^z is the existing number of incumbent firms, MA_t^z the "financial attractiveness" of the industry, $1 \leq o \leq 1$ is a mix balance parameter, and π_t^z is a random draw from a uniform distribution on the fixed support $[\underline{x}_2, \bar{x}_2]$. The number of entrants stochastically depends on the number of incumbents (recalling a spin-off process of the former from the latter) with the financial conditions influencing the decision of would be entrants.

The industry-specific "financial attractiveness" MA_t^z in period t is defined as:

$$MA_t^z = MC_t^z - MC_{t-1}^z \qquad \text{(bounded to } [\underline{x}_2, \bar{x}_2]). \tag{2}$$

MC_t^z is calculated on firms' balance sheets as the (log) ratio between the aggregate stocks of liquid assets $NW_{y,t}$ (bank deposits) and bank debt $Deb_{y,t}$:

$$MC_t^z = \log\,(\sum_y NW_{y,t-1}) - \log\,(\sum_y Deb_{y,t-1}), \tag{3}$$

in each sector, $y \in \{i,j\}$, accordingly. So, MC_t^z measures the sectoral liquidity-to-debt ratio and thus the tightness of the credit market, and MA_t^z is a proxy to its dynamics. Correspondingly, negative (positive) values of MA_t^z represent leveraged (deleveraged) markets, meaning that debt is growing faster (slower) than the accumulation of cash equivalents. This means that whenever the overall liquidity-to-debt ratio is shrinking would-be firms are more inclined to enter, and vice versa.

The adopted formulation for the entry process tries to model some well-known facts in the industrial dynamics and business cycle literature: (i) the number of entrants is roughly proportional to the number of incumbent firms (Geroski, 1991, 1995), (ii) entry is affected by the easiness of access to credit (Kerr and Nanda, 2009; Bertrand et al., 2007), and (iii) the process is pro-cyclical (Gomis and Khatiwada, 2017; Lee and Mukoyama, 2015).

3.3 The labor market and skills dynamics

The labor market in the model implements a fully decentralized search and hiring process between workers and firms (more on that in Dosi et al., 2016b, 2017c). The aggregate supply of labor L^S is fixed and all workers are available to be hired in any period. Moreover, also the labor market is characterized by imperfect information. When unemployed, workers submit a certain number of job applications to firms. Employed workers may apply or not for better positions, according to the institutional setup (see Section 3.5 below). Larger firms, in terms of market share, have a proportionally higher probability of receiving job applications, which are organized in separated, firm-specific queues. Firms decide about their individual labor demand based on the received orders (capital-good sector), the

9 In the consumption-good market the replicator captures the law of motion which regulates the pace of adjustments in market shares among the ever-changing heterogeneous competitors. On the robustness of the empirical properties generated by the replicator dynamics, see Dosi et al. (2017e).

expected demand (consumption-good sector), and the expected labor productivity levels. Considering the number and the productivity of the already employed workers, firms decide to (i) hire new workers, (ii) fire part of the existing ones, or (iii) keep the existing labor force. Each hiring firm defines a unique wage offer for the applicant workers, based on its internal conditions and the received applications. Workers select the best offer they get from the firms to which they submitted applications, if any. If already employed (depending on the institutional regime), they quit the current job if a better wage offer is received. There is no second round of bargaining between workers and firms in the same period, and, so, firms have no guarantee of fulfilling all the open positions (no market clearing). Moreover, there is no firing or hiring transaction costs.

We extended the K + S model to account for the process of workers' skills accumulation and deterioration. Such a process is driven by the worker-specific job tenures, assuming learning-by-doing mechanism when employed and a gradual deterioration of skills while unemployed, and assuming firms keep introducing new techniques all the time, deprecating the skills of unemployed workers. The skill level $s_{\ell,t} > 0$ of each worker ℓ evolves over time as a multiplicative process:

$$s_{\ell,t} = \begin{cases} (1+\tau)s_{\ell,t-1} & \text{if employed in } t-1 \\ \dfrac{1}{1+\tau}s_{\ell,t-1} & \text{if unemployed in } t-1, \end{cases} \tag{4}$$

with the learning rate $\tau \geq 0$ a parameter. As a consequence, when worker ℓ is employed her skills improve over time, as she becomes more experienced in her task. Conversely, unemployed workers lose skills. In particular, when a worker is hired, she may immediately acquire the minimum level of skills already present in the firm (the existing worker with the lowest skills), if above her present level. Also, workers have a fixed working life. After a fixed number of periods $T_r \in \mathbb{N}^*$ in the labor market, workers retire and are replaced by younger ones,[10] whose skills are equivalent to the current minimum level in the incumbent firms.

Workers' skills define their individual (potential) productivity $A_{\ell,t}$:

$$A_{\ell,t} = \frac{s_{\ell,t}}{\bar{s}_t} A_i^\tau, \qquad \bar{s}_t = \frac{1}{L^S} \sum_{\ell} s_{\ell,t}, \tag{5}$$

where $\bar{s}_t$ is the average worker skills level, and A_i^τ is the warranted productivity of the machinery vintage the worker operates. The ratio $s_{\ell,t}/\bar{s}_t$, or the worker normalized productivity, represents her ability to produce more (if $s_{\ell,t} > \bar{s}_t$) or less (otherwise) when using a certain machine technology, in relation to the warranted vintage productivity. Note that the sectoral aggregation over the firm-level effective productivities $A_{j,t}$ is a truly emergent properties of the model, resulting, simultaneously, from the technical innovation dynamics (mainly, the introduction of new vintages A_i^τ), the worker skills accumulation/deterioration process, and the effective demand, which guides firms when deciding $Q_{j,t}^d$, the capital stock dynamics, and the employed machine mix (see Appendix A for more details).

The influence of the workers' skills upon production reflects a learning by tenure/doing mechanism well established in the literature at least since the seminal contribution of Arrow (1962). On the empirical side, for the links between job tenure, capability accumulation, and firm productivity, see Zhou *et al.* (2011) and Lucidi and Kleinknecht (2009), among others.

3.4 Time line of events

In each simulation time step, which can be taken to roughly represent a quarter, firms and workers behavioral rules are applied according to the following time line:

1. machines ordered in the previous period (if any) are delivered;
2. capital-good firms perform R&D and signal their machines to consumption-good firms;
3. consumption-good firms decide on how much to produce, invest, and hire/fire;
4. to fulfill production and investment plans, firms allocate cash flows, and (if needed) borrow from bank;
5. firms send/receive machine-tool orders for the next period (if applicable);

10 In the start of the simulation, initial workers ages are randomly drawn in the integer range $[1, T_r]$ and all start from the same skills level.

Table 1. Main characteristics of tested policy regimes

	Fordist (baseline)	Competitive
Wage sensitivity to unemployment	Low (rigid)	High (flexible)
Workers search activity	Unemployed only	Unemployed and employed
Labor firing restrictions	Under losses only	None
Workers hiring priority	Higher skills	Lower payback
Workers firing priority	Lower skills	Higher payback
Unemployment benefits	Yes	Yes (reduced)
Minimum wage productivity indexation	Full	Partial

6. firms open job queues and job seekers send applications to them ("queue");
7. wages are set (indexation or bargaining) and job vacancies are partly or totally filled;
8. workers (employed and unemployed) update their skills;
9. government collects taxes and pays unemployment subsidies;
10. consumption-good market opens and the market shares evolve according to competitiveness;
11. firms in both sectors compute their profits, pay wages, and repay debt;
12. exit takes place, firms with near-zero market share, or negative net assets are eschewed from the market;
13. prospective entrants decide to enter according to the markets conditions; and
14. aggregate variables are computed and the cycle restarts.

3.5 Alternative labor market policy regimes

We employ the model described above to study two alternative policy regimes, which we call *Fordist* (our baseline) and *Competitive*.[11] The policy regimes are telegraphically sketched in Table 1 (see Table B3 in Appendix B for the regime-specific parameter values).

Under the *Fordist regime*, wages are insensitive to the labor market conditions and indexed on a convex combination between economy-wide and firm-level productivity growth. There is a sort of covenant between firms and workers concerning "long term" employment: firms fire only when their profits become negative, while workers are loyal to employers and do not seek for alternative jobs. When hiring/firing, firms aim to keep the more skilled worker. Labor market institutions contemplate a minimum wage fully indexed to the aggregate economy productivity and unemployment benefits financed by taxes on profits. Conversely, in the *Competitive regime*, flexible wages respond to unemployment in a decentralized labor market dynamics, and are set by means of an asymmetric bargaining process where firms have the last say. Employed workers search for better paid jobs with some positive probability and firms freely adjust (fire) their excess workforce according to their planned production. Hiring/firing workers by firms are based on a trade-off between skills and wages, using a simple payback comparison rule. The Competitive regime is also characterized by different labor institutions: minimum wage is only partially indexed to productivity, and unemployment benefits—and the associated taxes on profits—are relatively lower.

The simulation exercises in Section 5 are built so that there is a regime transition at a certain time step, capturing a set of labor market "structural reforms." This institutional shock is aimed at spurring flexibility on the relations among agents in the labor market and implies that the social compromise embodied in the Fordist regime is replaced by the Competitive one.

4. Empirical validation

The K + S model is able to generate endogenous growth and business cycles, emergent crises, and to reproduce a rich set of macro (e.g., relative volatility, co-movements, etc.) and micro (firm size distributions, firm productivity dynamics, etc.) stylized facts (see Dosi *et al.*, 2010, 2013, 2015, 2017b). The detailed list of empirical

11 The two regimes roughly capture two alternative *wage-labor nexus* in the language of the *Regulation Theory* (see, within a vast literature, Boyer and Saillard, 2005 and Amable, 2003).

Table 2. Stylized facts matched by the K + S model at different aggregation levels

Microeconomic stylized facts	Aggregate-level stylized facts
Skewed firm size distributions	Endogenous self-sustained growth with persistent fluctuations
Fat-tailed firm growth rates distributions	Fat-tailed GDP growth rate distribution
Heterogeneous productivity across firms	Endogenous volatility of GDP, Consumption, and investment
Persistent productivity differentials	Cross-correlation of macro variables
Lumpy investment rates of firms	Pro-cyclical aggregate R&D investment
Heterogeneous skills distribution	Persistent and counter-cyclical unemployment
Fat-tailed unemployment time distribution	Endogenous volatility of productivity, unemployment, vacancy, separation, and hiring rates
	Unemployment and inequality correlation
	Pro-cyclical workers skills accumulation
	Beveridge curve
	Okun curve
	Wage curve
	Matching function

regularities matched by the model is reported in Table 2. In addition, the labor-enhanced version of the model (Dosi *et al.*, 2016b, 2017c), which explicitly accounts for microeconomic firm–worker interactions, has already proved to be able to robustly reproduce most of the labor market macro empirical regularities (cf. the bottom part of Table 2).[12]

The extensions to the K + S model proposed here add some new empirical regularities matched by the model. First, the new labor force learning dynamics produces fat-tailed worker-level skill distributions and firm-level productivity ones, consistent with the empirical evidence suggesting the presence of both firm- and worker-specific ample heterogeneity. Second, the more realistic entry dynamics increases the number of variables that match the cross-correlation/lag structures among aggregate macro indicators. Table 3 shows the time series correlation structure of firms net entry (entries minus exits) in the market, total bank debt, and average liquidity-to-sales ratios with respect to the GDP. These and the other macro variables correlation structures (not presented) seem reasonably in line with empirical evidence, as detailed in Dosi *et al.* (2010).

5. At the roots of hysteresis

Let us study the emergence of hysteresis in our model, addressing its possible causes and discussing its consequences for the economic dynamics. We will first study *inter-regime* long-run hysteresis (cf. Figure 1). We will then analyze the emergence of *intra-regime* (transient) hysteresis (Section 5.2).

5.1 Regime change: super-hysteresis

We begin with the long-run dynamics of the model, when affected by an institutional shock, namely, the introduction of "structural reforms" aimed at increasing the flexibility of the labor market, leaving however *untouched the technological fundamentals*. In our policy typology, the reforms are supposed to move the labor market regime from a Fordist to a Competitve setup (see Section 3.5 above). In that, we are also implicitly testing the insider–outsider hypothesis of hysteresis proposed by Blanchard and Summers (1987). In our model, the transition from a Fordist toward a Competitive type of labor relations captures the structural reforms, aimed at achieving both numerical (easier firing) and wage flexibility (wages more respondent to unemployment), as illustrated in Table 1.[13] The normative

12 For a detailed discussion upon the configurations and the parameter settings producing the above mentioned stylized facts, we refer to Dosi *et al.* (2010, 2017c). In the following we focus on the innovation, entry, and skills processes, and on the related variables and parameters.

13 Indeed, the change of the political structure and of the balance of power between capitalists and workers and the related results of a class struggle are phenomena which, while with profound economic roots, did occur at the

Table 3. Correlation structure with respect to GDP on selected variables

Fordist	$t-4$	$t-3$	$t-2$	$t-1$	0	$t+1$	$t+2$	$t+3$	$t+4$
Net entry	0.09	0.13	0.14	0.07	−0.05	−0.18	−0.25	−0.25	−0.17
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Total firm debt	0.21	0.29	0.34	0.35	0.30	0.21	0.11	0.02	−0.03
	(0.02)	(0.03)	(0.03)	(0.04)	(0.04)	(0.04)	(0.04)	(0.03)	(0.02)
Liquidity-to-sales	−0.12	−0.31	−0.52	−0.65	−0.66	−0.51	−0.26	−0.00	0.19
	(0.03)	(0.03)	(0.02)	(0.03)	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)
Competitive	$t-4$	$t-3$	$t-2$	$t-1$	**0**	$t+1$	$t+2$	$t+3$	$t+4$
Net entry	0.07	0.12	0.15	0.15	0.11	0.03	−0.07	−0.16	−0.21
	(0.02)	(0.02	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Total firm debt	0.11	0.11	0.08	0.03	−0.03	−0.08	−0.09	−0.07	−0.03
	(0.03)	(0.04	(0.04)	(0.03)	(0.03)	(0.03)	(0.02)	(0.03)	(0.03)
Liquidity-to-sales	−0.24	−0.50	−0.72	−0.85	−0.83	−0.64	−0.35	−0.02	0.25
	(0.02)	(0.01	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)

Note: All results significant at 5% level. MC standard errors in parentheses. Non-rate series are Baxter–King bandpass-filtered (6, 32, 12).

implication of such hypothesis is the advocacy of a more flexible labor market, where unions have lower bargaining power in the wage formation process, with the aim of making wages more respondent to unemployment conditions.

In Figure 3, we report the time series of the main macroeconomic variables in the two regimes.[14] The institutional shock occurs at time $t=100$ (the vertical dotted line). The widening GDP gap between the two regimes, as presented in Figure 3A, shows how the structural reforms determine *super-hysteresis* (i.e., a permanently lower growth rate of the GDP), whereby the effects propagate in the very long run (see also Dosi *et al.*, 2017c, 2016b). The actual level of the long-run capacity utilization increases from the 85% to 90% after the introduction of the Competitive regime (cf. Figure 3B), hinting at a process of underinvestment due to the steeper fluctuations in investments opportunities for firms. In the Competitive regime, as a result of the more flexible wage dynamics, increased GDP volatility, and their effect on the aggregate demand, firms reduce their average expansionary investments, which depend on the difference between (demand-led) desired and installed production capacity (see Equation (19) in Appendix A), pushing down the number of machines ordered from the capital-good sector. Therefore, firms decrease the gap between the effective production and the potential capacity, leading to a cyclical surge in the capacity utilization which tends to yield self-rationing. Capital accumulation is slower when structural reforms are in place: the long-run growth rate falls from 1.55% to 1.44% per period. Figure 3C shows the dynamics of unemployment and vacancy rates, which are negatively correlated, consistent with a Beveridge Curve, while unemployment is significantly higher in the Competitive regime. The negative effects of structural reforms spill over the long-run: the number of successful innovations in the capital-good sector takes a lower trajectory (Figure 3D), and the average level of workers skills is significantly reduced (Figure 3E). Finally, the trend of the net entry[15] of firms in the market is more turbulent after the reforms, also as a consequence of a higher level of volatility in credit conditions (Figure 3F).[16]

The different performance of the two regimes is quantitatively summarized in Table 4, which presents the averages, the ratios between selected variables of the two setups, and the *P*-values for a *t* test comparing the averages. The results confirm, at a 5% significance level, that after the introduction of structural reforms the short- and long-run performance of the economy significantly worsens. Note that as the technological configuration of the model is

sociopolitical level: the Thatcher–Reagan regime change has been an exogenous political transformation. Modeling the triggering mechanisms leading to the end of the welfare system is thus well beyond the scope of this article.

14 The presented series are the averages of 50 Monte Carlo simulation runs, over 500 periods. The initial 100 "warm-up" periods are not presented.

15 Note that the use of the two-sided Hodrick-Prescott (HP) filter artificially produces the diverging patterns of the two curves before time 100.

16 As discussed in Section 3.2, entry decision in the model is also driven by the average financial conditions of the firms in each sector.

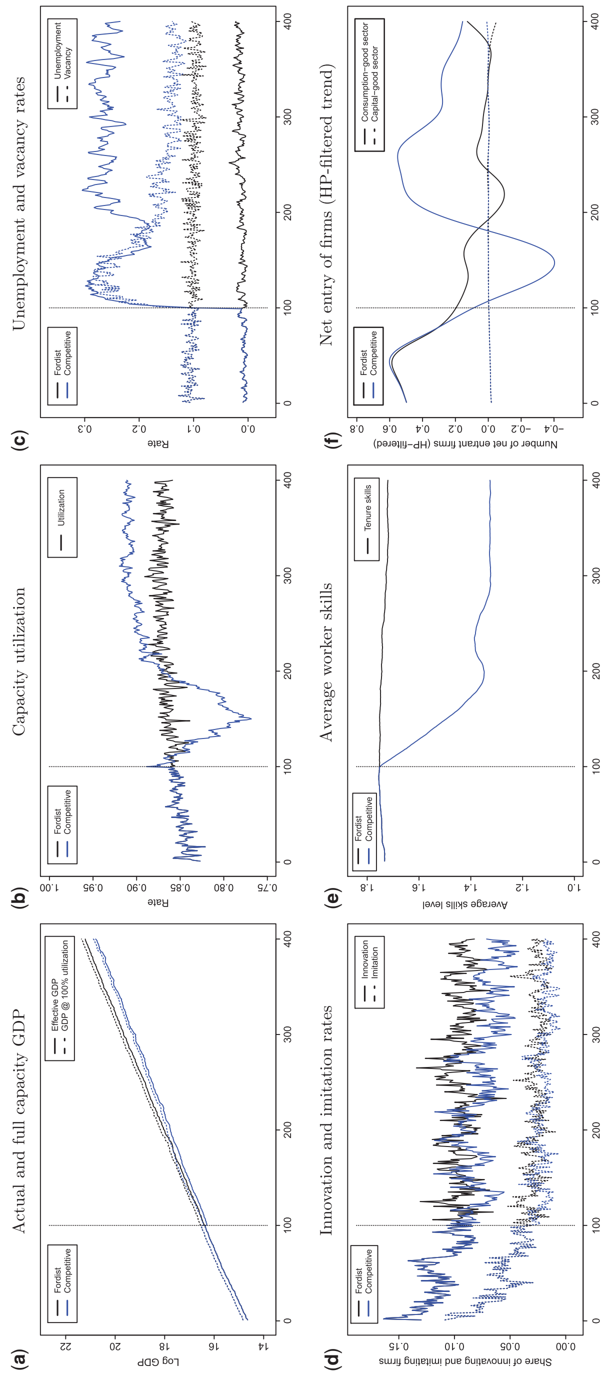

Figure 3. Macroeconomic dynamics in alternate policy regimes. Lines represent 50 MC runs averages (Fordist: black; Competitive: blue/gray).

Table 4. Comparison between policy regimes

Time series	Fordist (1)	Competitive (2)	Ratio (2)/(1)	*P*-value
GDP growth rate	0.0148	0.0135	0.9118	0.044
Capacity utilization	0.8712	0.9038	1.0374	0.000
Productivity growth rate	0.0147	0.0134	0.9084	0.034
Innovation rate	0.0937	0.0719	0.7677	0.001
Imitation rate	0.0253	0.0189	0.7476	0.004
Unemployment rate	0.0152	0.2640	17.400	0.000
Vacancy rate	0.0976	0.1439	1.4749	0.000
Worker tenure	27.861	4.9561	0.1779	0.000
Worker skills	1.7288	1.3418	0.7762	0.000
Wages standard deviation	0.0618	0.1710	2.7672	0.000

Note: Averages for 50 MC runs in period $[200, 400]$ (excluding warm-up). *P*-value for a two-means *t*-test, H_0: no difference between regimes.

invariant between the two regime specifications, the differences in terms of productivity, innovation, and imitation rates are entirely caused by the institutional shock.[17]

What are the drivers of the soaring super-hysteresis in the model? The huge surge in unemployment reflects the widening gap between the long-run dynamics of real wages in the two regimes,[18] which, in turn, leads to the emergence of Keynesian unemployment due to the contraction of aggregate demand, the slowdown in skills accumulation and actual productivity growth. Figure 4 shows the box-plot comparison between the Monte Carlo simulation runs for the two regimes, for the long-term consequences in terms of the innovation and imitation rates, productivity growth, job tenure, workers' skills, and net entry of firms (see Section 2). The results in the first row of plots (Figure 4A–C) indicate a reduction in the innovation and imitation rates in the majority of the simulation runs—the latter variables are calculated as the rate of successful innovators and imitators in the capital-good sector—and, as a consequence, in the productivity growth rate. This is an indirect outcome of the fall in the aggregate demand, which yields lower R&D expenditure by firms.[19] In the same direction, the results in the second row of Figure 4 show the quite significant fall on the average tenure period (Plot d) and the ensuing slower pace of the workers skills accumulation (Plot e), which, in turn, also has a direct and negative effect on the growth of productivity. Finally, the dynamics of net entry (number of entrants minus the exiting firms) is presented in Plot f.[20] In the Competitive regime the financial cycle is amplified due to the increased volatility, exacerbating the entry dynamics: in good times there are more entrants in Competitive than in the Fordist regime, which exhibits a stabler financial cycle, while the opposite occurs in bad times. Both emergent phenomena, i.e. the more pronounced leverage cycle and the tighter availability of credit, have been empirically documented by Ng and Wright (2013) from the last three recessions (1990, 2001, and 2007).

The transmission channels in the model operate through both *numerical* and *wage flexibility*. First, higher numerical flexibility, where workers are more freely fired, determines a sharp drop in workers job tenure and, indirectly, has a negative effect on skills accumulation and, consequently, on productivity. Not only the firing rule but also the firing order criteria affect the dynamics of productivity growth. In the Fordist regime, firms first hire (fire) workers with higher (lower) skills.[21] Conversely, in the Competitive case, firms use the skills-to-wage "payback" ratio as a

17 In accordance with the behavioral rules set in the model (cf. Appendix A), the dynamics of innovation, of imitation, of new machines introduction, and, consequently, of the firms productivity growth is directly affected by the overall macroeconomic conditions, including those directly impacted by the reforms. This creates a (potentially hysteretic) reinforcing feedback process between the macro and the technological domains, which in part explains the observed results.

18 The real wage growth rates are 1.47% and 1.35% per period, respectively.

19 See Appendix A for details on the innovation process.

20 The diverging trend before time $t = 100$ is due to the two-sided HP filter we employ to detrend the series.

21 This is a necessary consequence of the firms unilaterally decided and homogeneously applied wage adjustments, so skills are the only heterogeneous metric among workers in a Fordist firm.

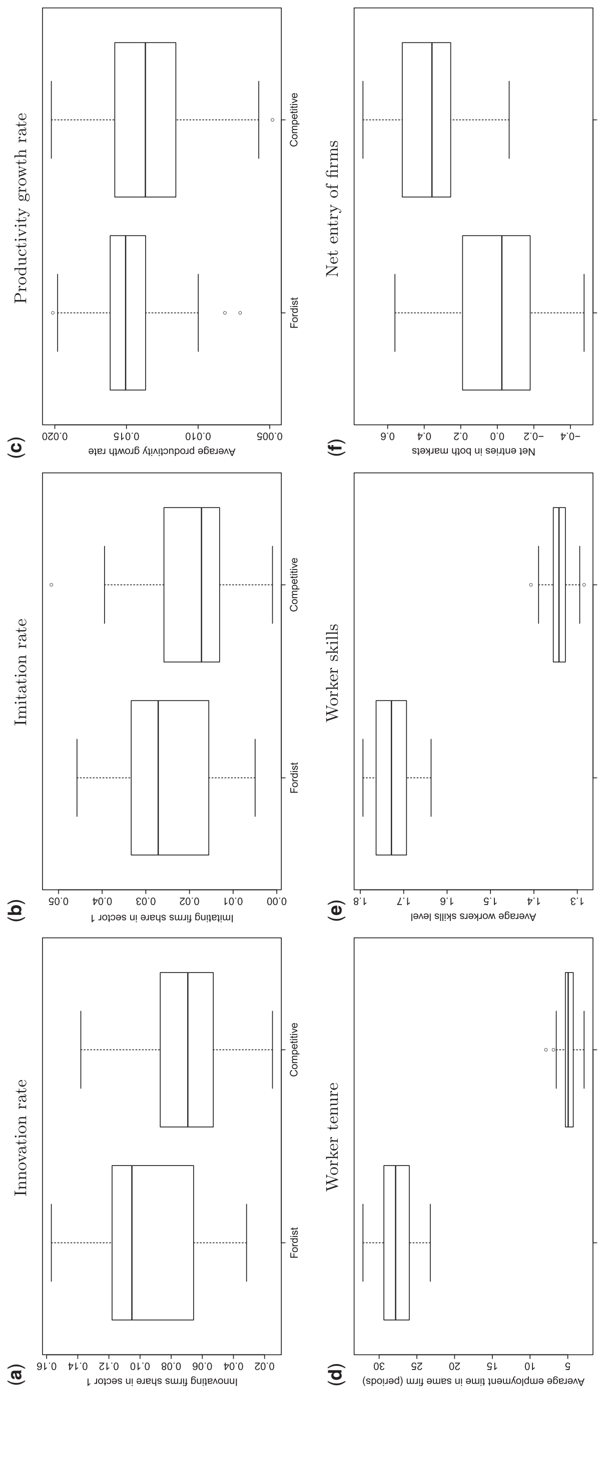

Figure 4. Performance comparison between policy regimes (Fordist: left; Competitive: right). Summary statistics for 50 MC runs in period [200, 400] (excluding warm-up). Bar: median; box: second to third quartile; whiskers: maximum–minimum; dots: outliers.

decision guide to preferentially hire (fire) workers with superior (inferior) short-term "returns." Such a behavior has a negative impact on the aggregate skill level of the incumbent workers over time. On the other hand, higher wage flexibility, by limiting the wage indexation upon the productivity gains, causes a straightforward drop in the aggregate demand via the reduced consumption of workers. In turn, the shrinking sales opportunities drive a fall in investment and labor demand, which induces more unemployment, characterizing a typical Keynesian feedback-amplified downturn. Moreover, the slower economy also impacts upon the entry/exit and the innovation/imitation rates, via the overall cut in total R&D expenditure and the higher volatility in the number of operating firms. In fact, Table 3 shows the significant level of correlation between the business cycle and the net entry of firms in the market.

The severe effects of super-hysteresis are particularly well illustrated by the probability distributions for the time unemployed workers need to find a new job, presented in Figure 5.[22] As shown by the huge increase in the distribution support, long-term unemployment is by far higher in the Competitive case.[23]

To sum up, our experiments generically yield super-hysteresis stemming from an institutional shock. Indeed, institutions are a "carrier of history" (David, 1994) also here. However, contrary to the insider–outsider hypothesis (Blanchard and Summers, 1987), "pro-market" institutions bear a *negative* hysteretic effect. The model suggests that structural reforms aimed at increasing the flexibility in the labor market may well spur even more hysteresis instead of reducing it. Granted that, in the next section, we focus on *intra-regime* hysteresis phenomena.

5.2 Detecting intra-regime hysteresis

Assessing the emergence of intra-regime hysteresis is not a trivial task, as there is no conclusive test or even widely accepted criteria for this. However, there are several properties and techniques which do help uncover particular aspects of hysteresis. In the following, we present a set of analytical methods, summarized in Table 5, which provide evidence of the presence of hysteretical properties in the K + S model. In line with the literature, we study whether the time series generated by the model present evidence of (i) remanence, (ii) persistency, (iii) nonlinearity, (iv) path dependency, and (v) super-hysteresis. Needless to say, these properties are to some degree overlapping.

Figure 6 illustrates the number of periods (gray area) necessary to put the economy back to the pre-crisis growth trend (dashed line) in typical simulation runs.[24] The analysis is inspired by previous work (Blanchard *et al*., 2015) and simply performs an extrapolation of the long-run GDP trend to detect the recovery from crises under the possible presence of hysteresis. The results show the coexistence of shorter business cycle downturns with longer, hysteretical crises, requiring significant more times for the economy to recover. Note also the presence of super-hysteresis, revealed by the different slopes of the peak-to-peak GDP trends (dashed lines).

Table 6 reports the average recovery duration for both the GDP and the mean unemployment time (the average period a worker takes to find a new job). While the duration of the GDP trend recovery is similar among regimes (around 16 quarters), the unemployment time takes almost five times more to return to its pre-crisis level in the Competitive case. To better assess the severity of the crises, we also track the peak GDP trend deviation during the recovery period (the farther the GDP gets from the pre-crisis trend) and the accumulated GDP losses in comparison to the trend (the crisis "cost"). The model robustly shows how Competitive regime crises are about twice deeper than in the Fordist scenario. The accumulated GDP loss comparison leads to a similar conclusion.

In Table 7, we report a set of statistical tests to detect unit-roots vs. stationarity (Augmented Dickey–Fuller/ADF, Phillips–Perron/PP, and Kwiatkowski–Phillips–Schmidt–Shin/KPSS tests), i.i.d. vs. nonlinear processes (Brock–Dechert–Scheinkman/BDS test), and ergodicity (Kolmogorov–Smirnov/KS and Wald–Wolfowitz/WW tests). Except for the WW case, the tests are applied for individual Monte Carlo simulation runs (or multiple run-pair combinations, in the case of KS) and, so, the results present the frequency of the rejection of the null hypothesis for the set of 50 runs at the usual 5% significance level (see Table 7 for the definition of H_0 in each case).

The results suggest that GDP, productivity, and wage growth rates more frequently exhibit stationary (no unit-roots) behaviors in both regimes. More borderline, the unemployment rate time series seems to be more commonly

22 Note the log scale in the y-axis.

23 The maximum notional unemployment time is 120 periods, equivalent to the working life in the model (parameter T_r).

24 A crisis is defined by a 3% drop of the GDP in a single period which is not recovered in the next three periods. The pre-crisis level is calculated as the average GDP for the four periods before the crisis and the trend, and as the output of an HP filter at the period just before the crisis. The crisis is considered recovered when the GDP reaches back the pre-crisis trend level.

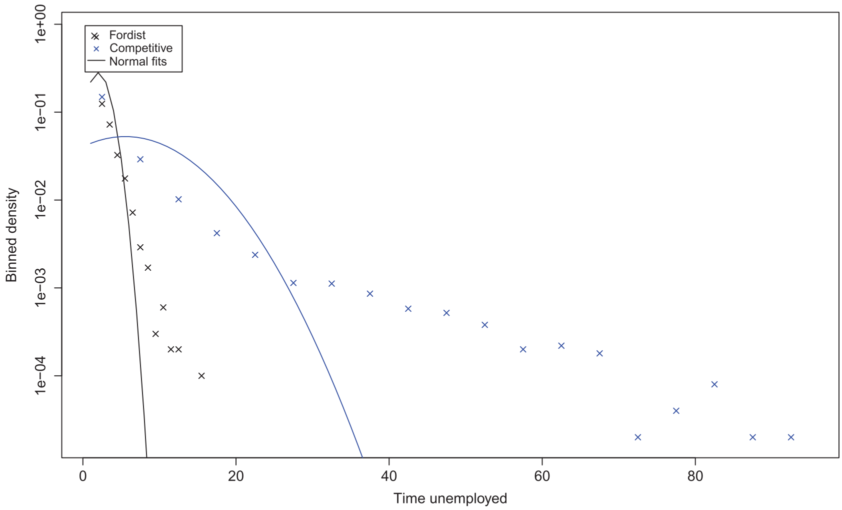

Figure 5. Actual probability distribution vs normal fit of worker unemployment time. Each *t* corresponds to a quarter.

Table 5. Selected tests to evaluate hysteretic properties in times series

Property	Test	Reference
Remanence	Duration of recovery of employment and GDP after crises	Jaimovich and Siu, 2012
Persistency	Unit-root tests for stationarity	Blanchard and Summers, 1986
Nonlinearity	BDS test	Broock *et al.*, 1996
Path dependence	Ergodicity tests	Wald and Wolfowitz, 1940
Super-hysteresis	Different GDP growth trend (slope) after crises	Blanchard *et al.*, 2015

stationary among simulation runs in the Fordist regime, while more likely non-stationary in the Competitive case. The nonlinearity test indicates a quite nuanced situation: the unemployment series is the one more frequently displaying nonlinear structure, particularly in the Competitive regime, while the wage growth rates series seem more likely to be i.i.d. processes. Finally, the less powerful KS test cannot reject ergodicity for the majority of run pairs tested, while WW indicates non-ergodicity of *all* series.

There are a few take-home messages from the tests. First, that mixed results, e.g., on ergodicity and stationarity, militate as such in favor of path dependency. In fact, they show the different statistical properties of alternative sample-paths: only an outright non-rejection of the null hypothesis could be claimed in support of the the lack of hysteresis. Second, but related, the tests aimed at the detection of some underlying, emergent, nonlinear structure are quite encouraging despite the limited length of the sample paths.[25]

Finally, we perform a global sensitivity analysis (SA) to explore the effects of alternative model parametrizations and to gain further insights on the robustness of our exercises on institutional shocks.[26] Of the 57 parameters and initial conditions in the K + S model, we reduce the relevant parametric dimensionality to 29, by means of an

25 The choice of the adequate time window length is quite relevant when analyzing hysteresis, as detailed in Section 2.1, and it is not driven by the availability of simulated data. For this reason we split the analysis in inter-regime hysteresis, where the patterns are of long-term type, and the intra-regime hysteresis. The analysis used in the literature to detect hysteresis is always performed for relatively short time spans (usually under 20 years). For comparability with empirical data, to check for the intra-regime hysteresis we restricted the time span to 50 runs, which is closer to the empirical time horizons. Note that taking longer time spans would simply "dilute" some hysteretic properties of the series, like non-ergodicity or non-stationarity.

26 For technical details on the global SA methodology, see Dosi *et al.* (2017d).

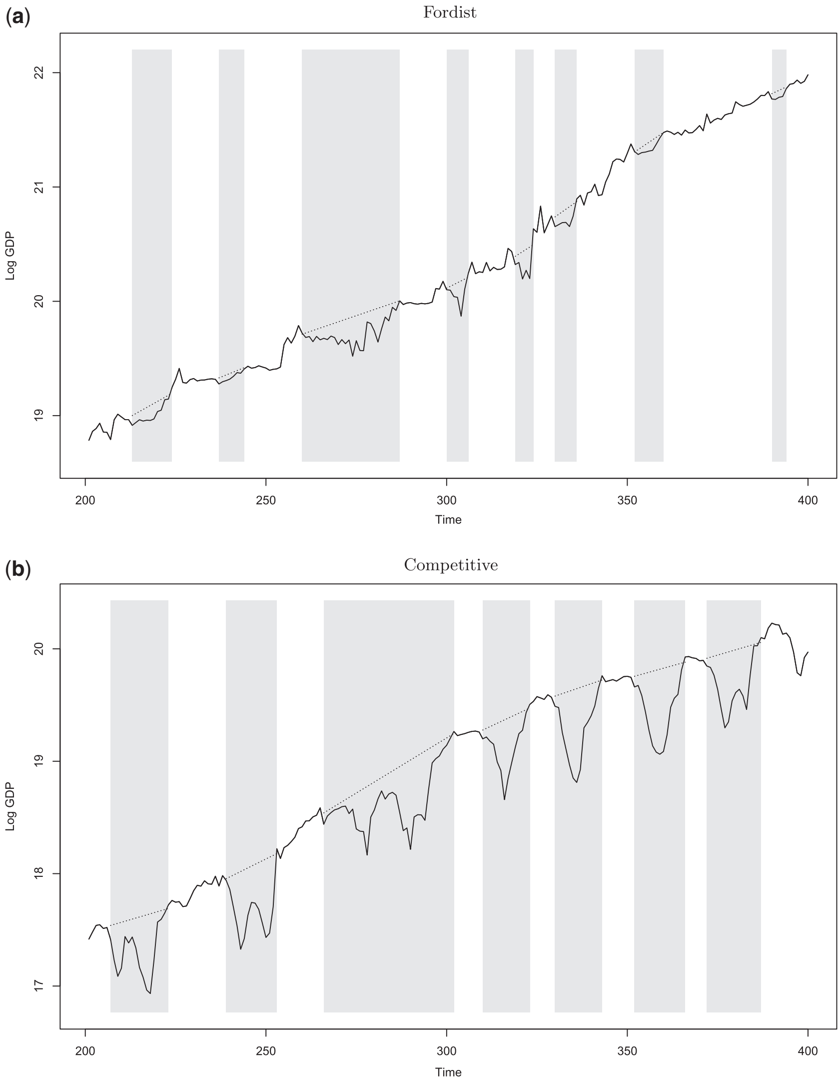

Figure 6. GDP recovery after crises. Typical simulation runs. Dashed line: pre-crisis trends; gray boxes: recovery periods.

Elementary Effect screening procedure which allows to discard from the analysis the parameters which do not significantly affect the selected model outputs.[27] All the parameters tested in the SA, their "calibration" values, as well the tests statistics, are detailed in Table B1 (Appendix B). To understand the effect of each of the 29 parameters over the selected metrics, we perform a Sobol decomposition.[28] Because of the relatively high computational costs to produce the decomposition using the original model, a simplified version of it—a meta-model—was built using the Kriging

27 Briefly, the Elementary Effects technique proposes both a specific design of experiments, to efficiently sample the parameter space under a one-factor-at-a-time, and some linear regression statistics, to evaluate direct and indirect (non-linear/non-additive) effects of parameters on the model results (Morris, 1991, Saltelli *et al.*, 2008).

28 The Sobol decomposition is a variance-based, global SA method consisting in the decomposition of the variance of the chosen model output into fractions according to the variances of the parameters selected for analysis, better dealing with nonlinearities and non-additive interactions than traditional local SA methods. It allows to disentangle both direct and interaction quantitative effects of the parameters on the chosen metrics (Sobol, 1993, Saltelli *et al.*, 2008).

Table 6. Comparison between policy regimes: crises, GDP and unemployment time recovery

	Fordist	Competitive
Number of crises	6.15	5.77
	(0.44)	(0.28)
Crises peak	0.23	0.51
	(0.01)	(0.02)
Crises losses	2.38	4.18
	(0.33)	(0.42)
Recovery duration		
-GDP	15.64	16.97
	(1.43)	(1.04)
-Unemployment time	6.83	31.22
	(0.55)	(9.04)

Note: Averages for 50 MC runs in period [200, 400] (excluding warm-up), MC standard errors in parentheses.

Table 7. Comparison between policy regimes: statistical tests for detecting hysteresis

Fordist	ADF	PP	KPSS	BDS	KS	WW
GDP growth rate	0.80	1.00	0.00	0.30	0.23	0.00
Productivity growth rate	0.76	1.00	0.02	0.44	0.12	0.00
Wage growth rate	0.60	1.00	0.12	0.16	0.40	0.00
Unemployment rate	0.40	0.60	0.16	0.50	0.33	0.01
Competitive	**ADF**	**PP**	**KPSS**	**BDS**	**KS**	**WW**
GDP growth rate	0.54	0.98	0.00	0.42	0.11	0.00
Productivity growth rate	0.64	1.00	0.02	0.62	0.19	0.00
Wage growth rate	0.42	1.00	0.14	0.30	0.38	0.02
Unemployment rate	0.24	0.00	0.26	1.00	0.49	0.00

Note: Frequencies of rejection of H_0 for 50 MC runs in period [300, 350] (excluding warm-up) except for WW test (*P*-value presented), at 5% significance. ADF/PP H_0: non-stationary—KPSS) H_0: stationary—BDS H_0: i.i.d., KS/WW H_0: ergodic.

method and employed for the Sobol SA.[29] The meta-model is estimated by numerical maximum likelihood using a set of observations (from the original model) sampled using a high-efficiency, nearly orthogonal Latin hypercube design of experiments (Cioppa and Lucas, 2007).

The main indicator used for the SA is the accumulated GDP losses during the crises' recovery periods (the crisis "cost"), as defined above. It seems a sensible choice, as it conveys information about both the duration and the intensity of the crises, as such among the key properties of hysteresis. Interestingly, this indicator is significantly influenced only by a limited set of parameters, and by *no initial condition*, including the learning rate parameter (τ), the retirement age (T_r), the replicator equation parameter (χ), the maximum technical advantage of the capital-good entrants (x_5), the minimum capital ratio (Φ_1) and the expected capacity utilization (u) of the consumption-good entrants.[30] The two parameters associated with the skills accumulation process, learning rate (τ) and retirement age (T_r), are jointly responsible for almost 80% of the variance of the losses indicator over the entire parametric space in both policy regimes.[31]

29 Summarizing, the Kriging meta-model "mimics" our original model by a simpler, mathematically tractable approximation. Kriging is an interpolation method that under fairly general assumptions provides the best linear unbiased predictors for the response of complex, nonlinear computer simulation models (Rasmussen and Williams, 2006, Salle and Yıldızoğlu, 2014).

30 All the equations and parameters are described in Sections 3.1 and 3.3 and in the Appendices.

31 The parameters calibration values, valid ranges, and the Sobol decomposition results are presented in Table B1 in Appendix B.

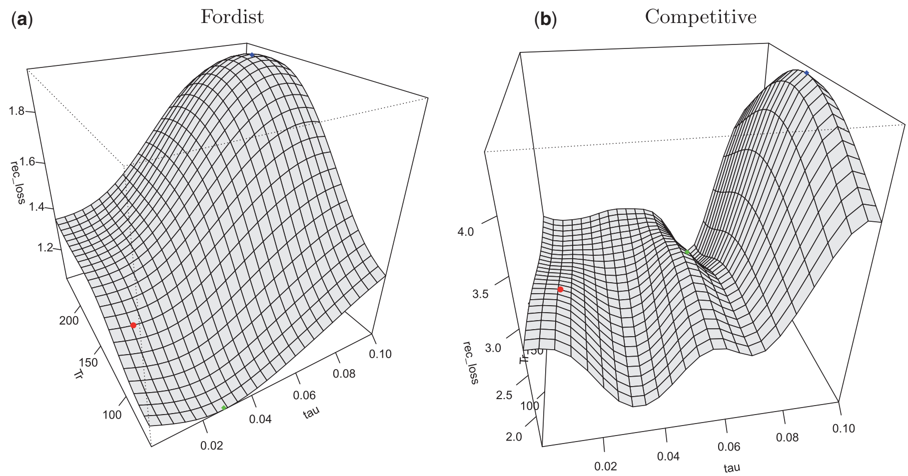

Figure 7. Global SA: response surfaces. Surfaces modelled using the Kriging meta-model. *z*-axis: recovery losses (*rec_loss*). Dot: calibration settings. Markers: maximum and minimum predicted crises losses.

Figure 7A and B presents an exploration of the model response surface, using the Kriging meta-model, for the two critical skill-related parameters. The rugged surfaces, in particular in the Competitive regime, clearly indicate the nonlinear nature of the system, in tune with the hysteretic properties of the model. The SA seems to suggest that the prominent parameters influencing the level of hysteresis observed in the losses indicator are those directly connected with the workers skills accumulation process (τ and T_r), the firm entry mechanism (Φ_1, u and x_5), and the market competitiveness (χ). Directly or in interaction among them, these five parameters account for 95% of the variation of the GDP crises losses in the model for the two scenarios. As can be seen in Figure 7, the Competitive regime tends to produce significant higher GDP crises losses irrespective of the model setup (notice that the peak losses in Plot (a), are at a lower z-axis level than the deepest valley in Plot (b)). Finally, the response surfaces in both regimes show that in general the higher the learning rate (τ), the higher is the accumulated GDP losses during the crises' recovery periods. The latter positive marginal effect hints at the fact that the higher the firm-specific capabilities, the more difficult is to rebuild the workers skills destroyed by a crisis, turning back to the pre-crisis level.

All in all, the statistical tests results indicate that model has a rather frequent tendency to show the properties usually associated with hysteresis in its main variables, in particular the unemployment rate, whenever hit by an endogenously produced crisis. Recoveries can take quite long times, and the losses experienced by the economy, both in terms of the GDP and the social cost of unemployment, are severe. It is also significant that such losses seem to *increase* after the introduction of structural reforms of the type discussed above.

6. Conclusions

The Great Recession has forced a revival of the notion of hysteresis, as such a short-hand for the possibility of multiple equilibria/paths either in some transient periods or even in the longer term. The evidence has been overwhelming: not only the level trends of GDP and unemployment but even the growth rates in many countries are still persistently below the pre-2008 figures.

Older candidates for the interpretation of such a behavior are unit-root processes in unemployment—as originally suggested by Blanchard and Summers (1986). But such interpretations are rather fragile in that they postulate the source of hysteresis in some *deviations of reality from the standard frictionless model*, e.g. the insider–outsider labor market rigidities.

Here we have analyzed an opposite perspective. In tune with an expanding tradition of scholars, we have discussed the notions of hysteresis and path dependence, identifying in coordination failures and persistent effects of aggregate demand upon productivity the main sources of long-term jumps across multiple growth trajectories. In doing that, we have presented an ABM which intertwines a Schumpeterian engine of growth and a Keynesian generation of demand, declined under two institutional labor market variants, labeled as Fordist and Competitive regimes. The transition from the Fordist to the Competitive regime captured "structural reforms" aimed at increasing labor market flexibility. Does the latter reduce hysteresis? Not at all.

The model is able to generically exhibit path dependence, nonlinearity, and non-ergodicity in its main macroeconomic variables, presenting both *inter-regime* and *intra-regime* hysteresis as a bottom-up emergent property. Moreover, the model suggests that both numerical and wage flexibility are quite prone to increase the hysteretic properties of the macroeconomic system.

The K + S model leaves scope for many potential avenues for further research, addressing the links between the functioning of the capital, consumer, and labor markets. In particular, a straightforward extension of the current article would be the study of the effects of active labor market policies, declined under alternative training programs and hiring/firing schemes. Yet, another venue of research concerns the effect of hysteresis upon labor force participation.

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Appendices

Appendix A

Capital- and consumption-good sectors and technical change

The technology of capital-good firms is (A_i^τ, B_i^τ). A_i^τ is the labor productivity of the machine-tool manufactured by i for the consumption-good sector, while B_i^τ is the labor productivity to produce the machine. Superscript τ denotes the technology vintage being produced/used. Given the monetary average wage $w_{i,t}$ paid by firm i, the unit cost of production is:

$$c_{i,t} = \frac{w_{i,t}}{B_i^\tau}. \tag{6}$$

With a fixed markup $\mu_1 \in \mathbb{R}^+$ pricing rule, prices $p_{i,t}$ are defined as:

$$p_{i,t} = (1 + \mu_1)c_{i,t}. \tag{7}$$

Firms in the capital-good industry "adaptively" strive to increase their market shares and their profits trying to improve technology via innovation and imitation. Firms invest in R&D a fraction $\nu \in (0, 1]$ of their past sales $S_{i,t-1}$:

$$RD_{i,t} = \nu S_{i,t-1}. \tag{8}$$

R&D activity is performed by workers exclusively devoted to this activity, whose demand is:

$$L_{i,t}^{R\&D} = \frac{RD_{i,t}}{w_{i,t}}. \tag{9}$$

Firms split their R&D workers $L_{i,t}^{R\&D}$ between innovation $(IN_{i,t})$ and imitation $(IM_{i,t})$ activities according to the parameter $\xi \in [0, 1]$:

$$IN_{i,t} = \xi L_{i,t}^{R\&D} \tag{10}$$

$$IM_{i,t} = (1 - \xi)L_{i,t}^{R\&D}. \tag{11}$$

Innovation is a two-step process. The first one determines whether a firm obtains or not access to an innovation—irrespectively of whether it is ultimately a success or a failure—through a draw from a Bernoulli distribution with parameter:

$$\theta_{i,t}^{in} = 1 - e^{-\zeta_1 IN_{i,t}}, \tag{12}$$

and parameter $\zeta_1 \in (0, 1]$. If a firm innovates, it may draw a new machine-embodying technology $(A_{i,t}^{in}, B_{i,t}^{in})$ according to:

$$A_{i,t}^{in} = A_{i,t}(1 + x_{i,t}^A), \tag{13}$$

$$B_{i,t}^{in} = B_{i,t}(1 + x_{i,t}^B), \tag{14}$$

where $x_{i,t}^A$ and $x_{i,t}^B$ are two independent draws from a Beta (α_1, β_1) distribution, $(\alpha_1, \beta_1) \in \mathbb{R}^{2+}$ over the fixed support $[\underline{x}_1, \bar{x}_1] \subset \mathbb{R}$.

Imitation also follows a two-step procedure. The access to imitation comes from sampling a Bernoulli with parameter:

$$\theta_{i,t}^{im} = 1 - e^{-\zeta_2 IM_{i,t}} \tag{15}$$

and $\zeta_2 \in (0, 1]$. Firms accessing the second stage are able to copy the technology (A_i^{im}, B_i^{im}) of one of the competitors. Finally, they select the machine to produce according to the rule:

$$\min\,[p_{i,t}^h + bc_{(A_i),t}^h], \quad h = \tau, in, im, \tag{16}$$

where $b \in \mathbb{R}^+$ is a payback parameter.

Firms in consumption-good sector do not conduct R&D; instead they access new technologies incorporating new machines to their existing capital stock $\Xi_{j,t-1}$. Firms invest according to expected demand $D^e_{j,t}$, computed by an adaptive rule:

$$D^e_{j,t} = g(D_{j,t-1}, \ldots, D_{j,t-h}), \quad 0 < h < t, \tag{17}$$

where $D_{j,t-h}$ is the actual demand faced by firms at time t–h ($h \in \mathbb{N}^*$ is a parameter and $g : \mathbb{R}^h \to \mathbb{R}^+$ is the expectation function, here an unweighted moving average over four periods). The corresponding desired level of production $Q^d_{j,t}$, considering the actual inventories from previous period $N_{j,t-1}$, is:

$$Q^d_{j,t} = (1+\iota)D^e_{j,t} - N_{j,t-1}, \tag{18}$$

being $N^d_{j,t} = \iota D^e_{j,t}$ the desired inventories and $\iota \in \mathbb{R}^+$, a parameter.

If the desired capital stock K^d_j —computed as a linear function of the desired level of production $Q^d_{j,t}$ —is higher than the current one, firms invest $EI^d_{j,t}$ to expand their production capacity:

$$EI^d_{j,t} = K^d_{j,t} - K_{j,t-1}. \tag{19}$$

Firms also invest $SI^d_{j,t}$ to replace machines by more productive vintages according to a fixed payback period ($b > 0$) rule, substituting machines $A^\tau_i \in \Xi_{j,t}$ according to its obsolescence as well as the price of new machines:

$$RS_{j,t} = \{A^\tau_i \in \Xi_{j,t} : \frac{p^*_{i,t}}{c^{A^\tau_i}_{j,t} - c^*_{j,t}} \leq b\}, \tag{20}$$

where $p^*_{i,t} \in \mathbb{R}^+$ and $c^*_{j,t} \in \mathbb{R}^+$ are the price and unit cost of production upon the new machines. Given the stock of machines $\Xi_{j,t}$, firms compute average productivity $\pi_{j,t}$ and average unit cost of production $c_{j,t}$, based on the average unit labor cost of production $w_{j,t}$ associated with each machine of vintage τ in its capital stock:

$$c^{A^\tau_i}_{j,t} = \frac{w_{j,t}}{A^\tau_i}. \tag{21}$$

Consumption-good prices are set applying a markup $\mu_{j,t}$ on average unit costs:

$$p_{j,t} = (1 + \mu_{j,t})c_{j,t}. \tag{22}$$

Markup changes are regulated by the evolution of firm market shares ($f_{j,t}$):

$$\mu_{j,t} = \mu_{j,t-1}(1 + \upsilon\frac{f_{j,t-1} - f_{j,t-2}}{f_{j,t-2}}), \tag{23}$$

with $\upsilon \in (0, 1)$. Firm market shares evolve according to a replicator dynamics:

$$f_{j,t} = f_{j,t-1}(1 + \chi\frac{E_{j,t} - \bar{E}_t}{\bar{E}_t}), \tag{24}$$

where the firms competitivity $E_{j,t}$ is defined based on the individual normalized prices $p'_{j,t}$ and unfilled demands $l'_{j,t}$:

$$E_{j,t} = -\omega_1 p'_{j,t-1} - \omega_1 l'_{j,t-1}, \quad \bar{E}_t = \frac{1}{F^2_t}\sum_j E_{j,t}f_{j,t-1}, \tag{25}$$

being $(\omega_1, \omega_1) \in \mathbb{R}^2$ parameters.

Labor market and search and match process

Labor demand in the consumption-good sector $L^d_{j,t}$ is determined by desired production $Q^d_{j,t}$ and the average productivity of current capital stock $A_{j,t}$:

$$L^d_{j,t} = \frac{Q^d_{j,t}}{A_{j,t}}. \tag{26}$$

In the capital-good sector, instead, $L^d_{i,t}$ considers orders $Q_{i,t}$ and labor productivity $B_{i,t}$. In what follows, only the behavior of the consumption-good sector (subscript j) is shown, as the capital-good firms operate under the same rules in the labor market, except they follow the wage offers from top-paying firms in the former sector.

Firms decide whether to hire (or fire) workers according to the expected production $Q^d_{j,t}$. If it is increasing, $\Delta L^d_{j,t}$ new workers are (tentatively) hired in addition to the existing number $L_{j,t-1}$. Each firm (expectedly) gets a fraction of the number of applicant workers $L_{a,t}$ in its candidates queue $\{\ell^s_{j,t}\}$, proportional to firm market share $f_{j,t-1}$. In terms of statistical expectations:

$$\mathrm{E}(L^s_{j,t}) = \omega L_{a,t} f_{j,t-1}, \tag{27}$$

where $\omega \in \mathbb{R}^+$ is a parameter defining the number of job queues each seeker joins, in average. Considering the set of workers in $\{\ell^s_{j,t}\}$, each firm selects the subset of desired workers $\{\ell^d_{j,t}\}$ to make a job (wage) offer:

$$\{\ell^d_{j,t}\} = \{\ell_{j,t} \in \{\ell^s_{j,t}\} : w^r_{\ell,t} < w^o_{j,t}\}, \quad \{\ell^d_{j,t}\} \subseteq \{\ell^s_{j,t}\}. \tag{28}$$

Firms target workers that would accept the wage offer $w^o_{j,t}$, considering the wage $w^r_{\ell,t}$ requested by workers, if any. Each firm hires workers up to its demand $\Delta L^d_{j,t}$, or to all workers in its queue, and the number of effectively hired workers (the set $\{\ell^h_{j,t}\}$) is:

$$\#\{\ell^h_{j,t}\} = \Delta L_{j,t} \le \Delta L^d_{j,t} \le L^s_{j,t} = \#\{\ell^s_{j,t}\}, \quad \Delta L_{j,t} = L_{j,t} - L_{j,t-1}. \tag{29}$$

The search, wage determination, and firing processes differ according to the policy regime. In the Fordist regime, workers never quit jobs and firms fire employees only under losses ($\Pi_{j,t-1} < 0$) and shrinking desired production ($Q^d_{j,t} < Q_{j,t-1}$), except if exiting the market. Only unemployed workers search for jobs. Additionally, lowest skilled workers are fired first, while higher skilled workers are preferred when hiring, as in this regime wages are not bargained. Firms offer a wage:

$$w^o_{j,t} = w^o_{j,t-1}(1 + WP_{j,t}) \quad \text{bounded to} \quad w^{max}_{j,t} = p_{j,t-1} A_{j,t-1}, \tag{30}$$

that is accepted by the worker if she has no better offer. The positive wage premium is is defined as:

$$WP_{j,t} = \psi_2 \frac{\Delta A_t}{A_{t-1}} + \psi_4 \frac{\Delta A_{j,t}}{A_{j,t-1}}, \quad \psi_2 + \psi_4 \le 1, \tag{31}$$

being A_t the aggregate labor productivity and $(\psi_2, \psi_4) \in \mathbb{R}^{2+}$ parameters. So, wages are linked to firm-specific performance and also to the aggregate productivity dynamics. $w^o_{j,t}$ is simultaneously applied to all firm's workers. $w^o_{j,t}$ is bounded to a maximum break-even wage $w^{max}_{j,t}$ (the 0 unit profits myopic expectation).

In the Competitive setting, firms freely fire workers and employees actively search for better jobs while employed, quitting when there is a better offer. When hiring or firing, firms give precedence to workers with a higher skills-to-wage ratio (s^ℓ_t / w^ℓ_t), contracting them first and dismissing last. The matching is done by a one-round bargaining process. Workers have a reservation wage equal to the unemployment benefit w^u_t they receive from the Government when unemployed, if any, and request a wage $w^r_{\ell,t}$ during the job application:

$$w^r_{\ell,t} = \begin{cases} w_{\ell,t-1}(1+\epsilon) & \text{if employed in t} - 1 \\ w^s_{\ell,t} & \text{if unemployed in t} - 1. \end{cases} \tag{32}$$

$w_{\ell,t-1}$ is the current wage for the employed workers, and $\epsilon \in \mathbb{R}^+$ is a parameter. Unemployed workers have a gradually shrinking satisfying wage $w^s_{\ell,t}$, accounting for their recent wage history:

$$w^s_{\ell,t} = \max\left(w^u_t, \frac{1}{T_s}\sum_{h=1}^{T_s} w_{\ell,t-h}\right), \tag{33}$$

being $T_s \in \mathbb{N}^*$, the time span parameter of the moving-average of the past income. An employed worker accepts the best offer $w^o_{j,t}$ she receives if it is higher than her current wage $w_{\ell,t}$. An unemployed worker accepts the best offer she gets, if any, as all offers are at least equal to the unemployment benefit w^u_t.

In all cases, Government establishes an institutional minimum wage w_t^{min}, as the lower bound to the firm wage setting behavior:

$$w_t^{min} = w_{t-1}^{min}(1 + \psi_2 \frac{\Delta A_t}{A_{t-1}}). \tag{34}$$

Model closure

Government taxes firms profits at a fixed rate $tr \in \mathbb{R}^+$ and provides a benefit w_t^u to unemployed workers which is a fraction of the current average wage:

$$w_t^u = \psi \frac{1}{L_{t-1}^D} \sum_{\ell=1}^{L_{t-1}^D} w_{\ell,t-1}, \tag{35}$$

where $\psi \in [0, 1]$ is a parameter, and L_t^D is the total labor demand. Therefore, the Government expenses are:

$$G_t = w_t^u(L^S - L_t^D). \tag{36}$$

Workers fully consume their income (if possible) and do not get credit. Accordingly, desired aggregate consumption C_t^d depends on the income of both employed and unemployed workers plus the desired unsatisfied consumption from previous periods $(C_{t-1}^d - C_{t-1})$:

$$C_t^d = \sum_\ell w_{\ell,t} + G_t + (C_{t-1}^d - C_{t-1}). \tag{37}$$

The model applies the standard national account identities by the simple aggregation of agents' stocks and flows. The aggregate value added by capital- and consumption-good firms Y_t equals their aggregate production Q_t^1 and Q_t^2, respectively (there are no intermediate goods). In turn, it is equal to the sum of the effective consumption C_t, the total investment I_t, and the change in firm's inventories ΔN_t:

$$Q_t^1 + Q_t^2 = Y_t = C_t + I_t + \Delta N_t. \tag{38}$$

For further details, see Dosi *et al.* (2010) and Dosi *et al.* (2017c).

Appendix B

Table B1. Model parameters and initial conditions, calibration values, minimum–maximum range for sensitivity analisys, Elementary Effects μ^* statistic, and Sobol decomposition direct and interaction effects indexes

Symbol	Description	Value	Minimum	Maximum	μ^*	Direct	Interaction
Policy							
φ	Unemployment subsidy rate on average wage	0.40	0.00	1.00	4.82	–	–
r	Interest rate	0.01	0.00	0.10	8.27	0.006	0.001
tr	Tax rate	0.10	0.00	0.30	4.24	0.001	0.001
(Λ, Λ_{min})	Prudential limit on debt (sales multiple/fixed floor)	(2, 20,000)	(1, 0)	(4, 100000)	(6.89, 2.07)	(–, –)	(–, –)
Labor market							
ϵ	Minimum desired wage increase rate	0.020	0.005	0.200	6.33	0.000	0.000
τ	Skills accumulation rate	0.010	0.001	0.100	11.0	0.714	0.030
T_r	Number of periods before retirement (work life)	120	60	240	3.96	0.032	0.012
T_s	Number of wage memory periods	0	1	8	0.66	–	–
(ω, ω_{un})	Number of firms to send applications (employed/unemployed)	(0, 5)	(1, 1)	(20, 20)	(2.87, 8.92)	(–, 0.002)	(–, 0.001)
(ψ_2, ψ_4)	Aggregate/firm-level productivity pass-trough	(0.50, 0.50)	(0.95, 0.00)	(1.05, 1.00)	(11.1, 5.38)	(–, –)	(–, –)
Technology							
η	Maximum machine tools useful life	20	10	40	10.9	0.000	0.002
ν	R&D investment propensity over sales	0.04	0.01	0.20	2.58	–	–
ξ	Share of R&D expenditure in imitation	0.50	0.20	0.80	9.78	–	–
b	Payback period for machine replacement	3	1	10	7.72	0.007	0.001
dim_{mach}	Machine-tool unit production capacity	40	10	100	7.88	0.014	0.002
(α_1, β_1)	Beta distribution parameters (innovation process)	(3, 3)	(1, 1)	(5, 5)	(8.96, 5.21)	–	–
(α_2, β_2)	Beta distribution parameters (entrant productivity)	(2, 4)	(1, 1)	(5, 5)	(5.89, 10.3)	(–, 0.000)	(–, 0.001)
(ζ_1, ζ_2)	Search capabilities for innovation/imitation	(0.30, 0.30)	(0.10, 0.10)	(0.60, 0.60)	(6.91, 4.91)	(–, –)	(–, –)
$[\underline{x}_1, \bar{x}_1]$	Beta distribution support (innovation process)	[−0.15, 0.15]	[−0.3, 0.1]	[−0.1, 0.3]	(4.16, 4.74)	(–, 0.012)	(–, 0.001)
Industrial dynamics							
γ	Share of new customers for capital-good firm	0.50	0.20	0.80	8.45	–	–
ι	Desired inventories share	0.10	0.00	0.30	5.98	0.000	0.001
μ_1	Markup in capital-good sector	0.05	0.01	0.20	7.76	0.000	0.001
o	Weight of market conditions for entry decision	0.50	0.00	1.00	3.80	–	–
χ	Replicator dynamics coefficient (competition intensity)	1.0	0.2	5.0	9.13	0.056	0.001
υ	Markup adjustment coefficient	0.04	0.01	0.10	5.05	–	–
u	Planned utilization by consumption-good entrant	0.75	0.50	1.00	5.35	0.034	0.001
x_5	Maximum technical advantage of capital-good entrant	0.30	0.00	1.00	8.97	0.030	0.001
$exit_1$	Minimum orders to stay in capital-good sector	1	1	5	3.90	–	–
$exit_2$	Minimum share to stay in consumption-good sector	10^{-5}	10^{-6}	10^{-3}	3.38	–	–

(continued)

Table B1. Continued

Symbol	Description	Value	Minimum	Maximum	μ^*	Direct	Interaction
$[\Phi_1, \Phi_2]$	Minimum/maximum capital ratio for consumption-good entrant	$[0.10, 0.90]$	$[0.00, 0.50]$	$[0.50, 1.00]$	$(5.43, 11.6)$	$(0.031, -)$	$(0.001, -)$
$[\Phi_3, \Phi_4]$	Minimum/maximum net wealth ratio for capital-good entrant	$[0.10, 0.90]$	$[0.00, 0.50]$	$[0.50, 1.00]$	$(8.68, 5.00)$	$(0.001, 0.003)$	$(0.001, 0.001)$
(ω_1, ω_2)	Competitiveness weight for price/unfilled demand	$(1.0, 1.0)$	$(0.2, 0.2)$	$(5.0, 5.0)$	$(7.97, 12.5)$	$(-, 0.004)$	$(-, 0.000)$
$[\underline{x}_2, \bar{x}_2]$	Entry randomness distribution support and limit	$[-0.15, 0.15]$	$[-0.3, 0.1]$	$[-0.1, 0.3]$	$(8.91, 10.9)$	$(0.002, 0.001)$	$(0.001, 0.002)$
$[F^1_{min}, F^1_{max}]$	Minimum/maximum number of capital-good firms	$[10, 100]$	$[10, 20]$	$[20, 100]$	$(15.3, 19.9)$	$(-, 0.001)$	$(-, 0.003)$
$[F^2_{min}, F^2_{max}]$	Minimum/maximum number of consumption-good firms	$[50, 500]$	$[50, 200]$	$[200, 500]$	$(5.90, 6.59)$	$(-, 0.014)$	$(-, 0.012)$
Initial conditions							
μ^2_0	Initial markup in consumption-good sector	0.20	0.10	0.50	10.54	0.003	0.001
K_0	Initial capital stock in consumption-good sector	800	200	3000	3.72	–	–
L^S_0	Number of workers	250,000	50000	100,0000	8.17	0.012	0.001
(F^1_0, F^2_0)	Initial number of capital/consumption-good firms	(20, 200)	(10, 50)	(100, 500)	$(6.39, 7.49)$	$(-, -)$	$(-, -)$
(NW^1_0, NW^2_0)	Initial net wealth in capital/consumption-good sector	(10,000, 5000)	(2000, 2000)	(50,000, 50,000)	$(5.62, 5.59)$	$(0.005, 0.001)$	$(0.008, 0.005)$

Note: Baseline policy-specific values (Fordist regime). SA statistics relative to GDP crises recovery losses indicator averages for both regimes.

Table B2. Stock-and-flow consistency: transaction flow matrix

	Workers	Capital-good firms		Consumption-good firms		Bank		Government	$\sum$
		current	capital	current	capital	current	capital		
Consumption	$-C$	$+C$							0
Investment		$+I$			$-I$				0
Government expenditures	$+G$							$-G$	0
Wages	$+W$	$-W^1$		$-W^2$					0
Profits, firms		$-\Pi^1$	$+\Pi^1$	$-\Pi^2$	$+\Pi^2$				0
Profits, bank						$-\Pi^b$	$+\Pi^b$		0
Debt interests		$-rDeb^1_{t-1}$		$-rDeb^2_{t-1}$		$+rDeb_{t-1}$			0
Deposits interests		$+rNW^1_{t-1}$		$+rNW^2_{t-1}$		$-rNW_{t-1}$			0
Taxes		$-Tax^1$		$-Tax^2$				$+Tax$	0
Change in debt			$+\Delta Deb^1$		$+\Delta Deb^2$		$-\Delta Deb$		0
Change in deposits			$-\Delta NW^1$		$-\Delta NW^2$		$+\Delta NW$		0
$\sum$	0	0	0	0	0	0	0	0^*	0^*

Note: (*) Government deficit/superavit is close to 0 in the long run.

Table B3. Regime-specific parameter values

Parameter	Description	Fordist	Competitive
ω	Number of firms to send applications	0	5
φ	Unemployment subsidy rate on average wage	0.4	0.2
T_s	Number of wage memory periods	0	4
r	Interest rate	0.010	0.005
tr	Tax rate	0.015	0.010