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., GDP, productivity, unemployment) emerges out of the decentralized interactions of heterogeneous firms and workers. Building upon the model in Dosi et al. (2016, 2017), we specify an endogenous process of accumulation of workers' skills and a state-dependent process of firms entry, studying their hysteretic impacts. Indeed, hysteresis is ubiquitous. However, this is not due to market imperfections, but rather to the very functioning of decentralised economies characterised 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 behaviour 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 labour markets dampen hysteretic dynamics by supporting aggregate demand, thus making the economy more resilient.

Keywords

Hysteresis, Aggregate Demand, Multiple Equilibria, Skills Deterioration, Market Entry, Agent-Based Model

JEL codes

C63, E02, E24

Resumo

Neste trabalho, desenvolvemos um modelo *agent-based*, onde a histerese nas principais variáveis macroeconômicas (por exemplo, PIB, produtividade, desemprego) surge de interações descentralizadas entre empresas e trabalhadores heterogêneos. Com base no modelo de Dosi et al. (2016, 2017), especificamos processo endógenos de acumulação de habilidades pelos trabalhadores e de entrada das empresas no mercado e estudamos seus impactos histeréticos. A histerese é onipresente nos resultados. No entanto, isso não se deve às imperfeições do mercado, mas sim ao próprio funcionamento das economias descentralizadas, caracterizadas por externalidades de coordenação e retornos crescentes dinâmicos. Assim, ao contrário da hipótese *insider-outsider* (Blanchard and Summers, 1986), o modelo não suporta as conclusões de que relações industriais rígidas possam promover o comportamento histérico no desemprego agregado. Pelo contrário, esta contribuição fornece evidências de que, durante recessões severas e o associado declínio da demanda agregada, fenômenos como a diminuição das taxas de investimento e inovação, a deterioração das habilidades e a diminuição da dinâmica de entrada são melhores candidatos para explicar o aumento do desemprego de longo prazo e o reduzido crescimento do produto. Nesse sentido, mercados de trabalho mais rígidos atenuam a dinâmica histerética ao apoiar a demanda agregada, tornando a economia mais resiliente.

Palavras-chave

Histerese, Demanda Agregada, Equilíbrio Múltiplo, Deterioração de Habilidades, Entrada no Mercado, Modelo Baseado em Agente

Área ANPEC

Área 6 - Crescimento, Desenvolvimento Econômico e Instituições

1 Introduction

In this work, we develop an agent-based model able to display the endogenous emergence of hysteresis out of the interaction of heterogeneous firms and workers. The paper focuses on both the causes and the consequences of the hysteretical properties of macroeconomic time series, including GDP, productivity, and unemployment. Further, refining upon Dosi et al. (2016, 2017), 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 different 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 non-linear responses of a system characterised by multiple equilibria or path-dependent trajectories. Even if Piscitelli et al. (2000) (p. 59-60) define the former two as *bastard* usages of the notion of hysteresis, they have been the most common in economics, at least. In a representative example, Blanchard and Summers (1986) famous paper used the second of the foregoing interpretations in attempt to explain the structural unemployment in the late 1980's in many European countries, at around 10% and quite far from the predicted 2-3% equilibrium level. Two alternative hypotheses were proposed by these authors in order 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 are less relevant in the wage determination process. In the latter case, unemployment duration can (a) induce a process of worker skills deterioration, implying that the long-term unemployed experiences a fall in their productivity; (b) trigger search discouragement in unemployed people, less re-employable, and so less prone to search in the labour market.

Together with the supply side channels emphasized from the eighties, some acknowledgement has gone to aggregate demand shocks conceived as potential sources of hysteresis in the current economic crisis. 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 one. The work suggests a sustained 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 recession, and some of them, like Greece, faced up to 30% *losses* in potential output.

The empirical detection of hysteresis, of course, goes together with the analysis of its determinants. Agent-based models (Tesfatsion and Judd, 2006; LeBaron and Tesfatsion, 2008) 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 "Keynes meets Schumpeter" family of models (Dosi et al., 2010, Napoletano et al., 2012, Dosi et al., 2013, Dosi et al., 2015, 2016, 2017), as we shall see, is able to generically yield hysteresis in the macro variables under scrutiny both *inter-regimes* and *intra-regimes*. Indeed, hysteresis is ubiquitous.

According to our analysis, hysteresis is not due to market imperfections but rather to the very functioning of decentralised economies characterised by coordination externalities and dynamic increasing returns. Contrary to what is suggested by Blanchard and Summers (1986), our model does

[1] See Fagiolo and Roventini (2012, 2017) for critical surveys on macro ABMs. See also Bassi and Lang (2016) for an agent-based model with investment hysteresis. For related ABMs which consider a decentralised labour market, see Dawid et al. (2014), Russo et al. (2015), Caiani et al. (2016) and Caiani et al. (2016), among the others.

not support the hypothesis that rigid industrial relations, via the insider-outsider channel, are the driving source of hysteresis in aggregate unemployment. On the contrary, more in line with Ball et al. (2014), our work indicates 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 labour markets, by supporting aggregate demand, do not foster hysteresis but rather dampen it, thus making the economy more resilient.

The paper is organised as follows. After this introduction, 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 behaviours in the macroeconomic variables. 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 in non-ergodicity. The very notion of multiple paths for the development of both socio-economic 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 expect to recover invariant properties of the system under investigation.

However, in tackling path-dependent phenomena in the social sciences, an intrinsic difficulty rests also in the fact that frequently only one of the many possible realizations of the system, dependent on its initial state, is empirically observed. In fact, is history-dependence only shaped by initial conditions or does it relate also 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?

In economics, the very notion of hysteresis has only been acknowledged with some scepticism and often in the most restrictive interpretations. In the 1980's and 1990's, a stream of literature has faced head-on the challenge of non-linearity of growth processes and thus the multiplicity of alternative paths and the related hysteretic properties (good examples are the contributions in Anderson et al., 1988 and Day and Chen, 1993).[2] However, such a stream of investigation was progressively marginalized, possibly due to its "revolutionary" theoretical implications, particularly in terms of equilibria selection and the welfare theorems. 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 their seminal contribution, 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 one.

Whether or not a (close to) unit-root process is an adequate signal of hysteresis has been strongly debated. Recently, 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

[2]The hysteretic properties of economic systems is also emphasized in the Post Keynesian literature: see Davidson, 1991, 1993.

the New Keynesian Wage Phillips Curve. In general, this modelling approach has been 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. The obvious dissatisfaction with the (linear) unit-root process approach is currently bringing a revival on the importance of the detection of nonlinearities in empirical macroeconomics, therefore questioning the widespread use of such methods. For example, Beaudry et al. (2016) do find evidence of cyclical recurrent patterns, not detectable when estimating auto-regressive linear stochastic models, while examining empirical time series like unemployment and working hours.

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 characterise hysteretic processes, namely, *non-linearity*, *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 socio-economic domain are, first, feedback mechanisms related to *coordination externalities*, and, second, amplification processes stemming from some form of *increasing returns*.[3] In particular, it is frequently derived from (i) positive feedbacks between levels of aggregate activities and innovative search, and (ii) powerful interactions between the aggregate demand and the 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 that *negative demand shocks exert persistent effects*, because less aggregate demand entails less innovative search, which in turn entails less innovation stemming from technological shocks (Stiglitz, 1994).

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 belief is the Frisch-like idea of the economy as a "pendulum", responding to exogenous shocks.[4] In this perspective, it seems almost a "miracle" that in the empirical literature one recently finds impulse response functions with multipliers significantly greater than one. 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, 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 deriving from austerity or labour market flexibilization policies, might yield *reduced long-term rates of growth*: this is what is shown in Dosi et al. (2016) and Dosi et al. (2016). 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.

[3] See Dosi and Virgillito (2016) for a further discussion.

[4] For an enticing reconstruction of the discussion between Frisch and Schumpeter, see Louca (2001).

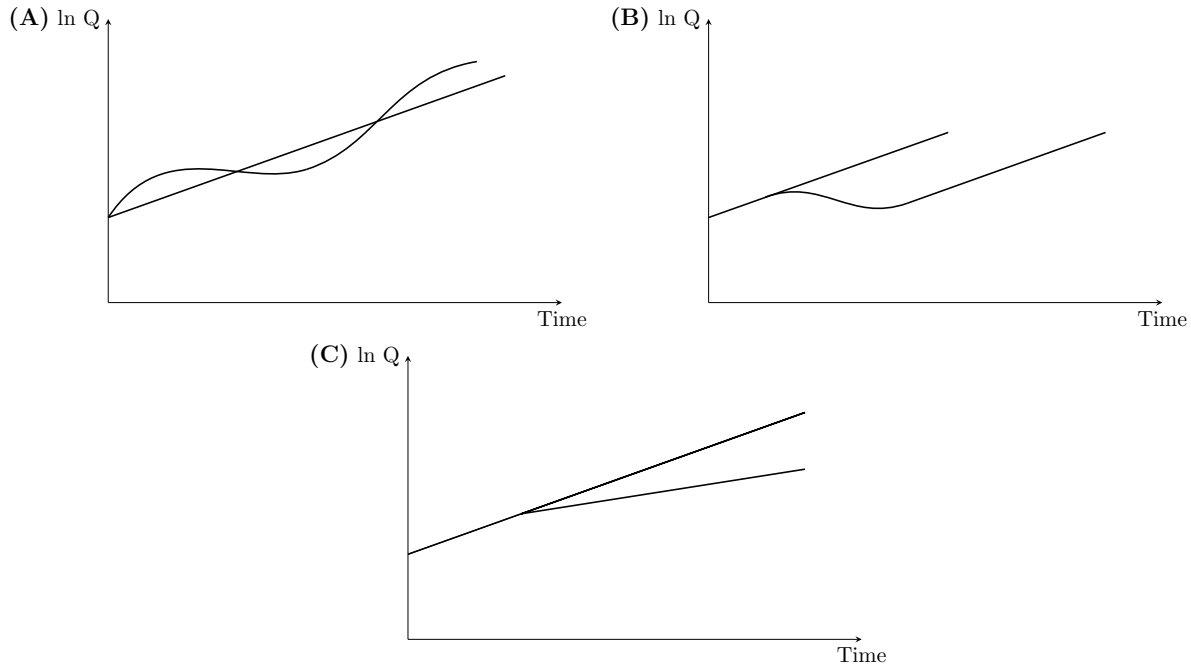


Figure 1: Effects of recessions: **(A)** short-run (no hysteresis), **(B)** long-run (hysteresis), **(C)** permanent/divergent (super hysteresis). Source (A and B): Stiglitz (1994), p. 123.

2.1 Innovation, diffusion and investment

At the empirical level, a *first* microeconomic channel[5] 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 slows down during crises. Reifschneider et al. (2015) document a drop in the yearly rate of growth of R&D expenditure in the U.S. from 3.6% during the pre-crises 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. (2016, 2017).

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. (2013) report that investments are *ultimately* affected by the dynamics of sales, rather than by the interest rate. According to their estimates, of the 23% total drop in investment during 2008-2009, "more than three-quarters (18.1%) can be explained by the drop in GDP and corporate profits in the fourth quarter of 2008" [ibid, p. 6].

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.

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

2.2 Entry dynamics

The *second* microeconomic channel is the declining entry rate of firms in the market, which has been recently investigated especially in the U.S., as discussed in Gourio et al. (2014). 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 the results of the tightening financial constraints, primarily affecting young firms. According to his estimates, the more finance-dependent entrant firms reduced their the 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 set-up costs, particularly during crises and the associated tight finance availability. In a Minskian perspective, on the other hand, periods of easy access to debt may induce a higher entry rate. Kerr and Nanda (2009) studied the effect of the banking deregulation in the U.S. upon the entry rate from the 1970s and estimated an increase of 10% in the start-ups rate after the reforms. Similar findings have been reported by Bertrand et al. (2007) at the industry level for France.

All in all, both in relatively bad or good times, the entry dynamics, affected by credit and other conditions, seems to be a potentially relevant source of hysteresis.

2.3 Skills deterioration

A *third* microeconomic channel which might trigger hysteresis is the workers' skills deterioration process. Once the economy enters a longer recessionary phase, firms tend to fire workers. During severe recessions, like the 2008 ongoing crisis, the incentive to firms to hire is significantly weakened, so unemployment which could be in principle temporary and cyclical turns out to be persistent, implying that many workers experience long unemployment periods. Unemployed workers, as they stop learning-by-doing and lose contact with the new practices and techniques being introduced by firms, gradually deteriorate their existing skills during the unemployment period. 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) analyse 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 six months of the peak of the downturn, during the last three crises employment continued to contract for about 20 months before turning around. Yet, at the end of 2013 employment had not returned to the pre-crisis level. Finally, 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. On a similar vein, 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 shocks upon skills and job-finding probabilities are yet another important candidate as a source of macroeconomic hysteresis.

3 The model

We build a general *disequilibrium*, stock-and-flow consistent, agent-based model, populated by heterogeneous firms and workers who behave according to bounded-rational rules. More specifically, we extend the Keynes Meets Schumpeter (K+S) model (Dosi et al., 2010) with decentralized interactions among firms and workers in both the product and the labour markets (Dosi et al., 2016, 2017), introducing an endogenous process of workers' skills accumulation and variable number of firms in the markets.

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.[6] 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 capital-good firms and labour in order to produce an 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 set 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.[7]

3.1 The entry and exit processes

We expanded the K+S model accounting for a variable number of firms in both the consumption- and the capital-good sectors (F_t^1, F_t^2). In the new version of the model, entry and exit are now independent processes. As before, firms leave the market whenever their market shares get close to zero or their net assets turn negative (bankruptcy). However, and in line with Dosi et al. (1995), we now define the number of entrants by means of the random variables b_t^1 and b_t^2:

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

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 market current financial attractiveness, $1 \leq o \leq 1$ is a mix balance parameter and π_t^z is a random draw from a uniform distribution on the fixed support $[\underline{x}_2, \bar{x}_2]$, representing a stochastic component in the entry process. This entry criterion states that the financial conditions do affect the decision of each firm evaluating to enter into the respective market, subject to a certain level of uncertainty, together with the current number of incumbent firms.

The market-specific entry 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 represents the overall sector's financial conditions, calculated based on firms' balance sheets as the (log) ratio between the aggregate stocks of liquid assets $NW_{y,t}$ (bank deposits) and bank debt $Deb_{y,t}$:

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

[6] The subscript t indicates time dependence, one time unit representing roughly one quarter. 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.

[7] Due to space restrictions, we do not present in details the firms', the workers' and the Government behavioural rules already set in the original model. For more details, including the model configuration, the timeline of events and the parameter set-up, please see Dosi et al., 2010 and Dosi et al., 2017.

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 debt is growing faster (slower) than the accumulation of cash equivalents. This means that whenever the incumbents' financial conditions are sound – the overall liquidity-to-debt ratio is shrinking – 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 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), (iii) the process is pro-cyclical (Gomis et al., 2017; Lee and Mukoyama, 2015).

3.2 The labour market and skills dynamics

The labour market in the model implements a fully-decentralized search and hiring process between workers and firms (more on that in Dosi et al., 2016, 2017). The aggregate supply of labour L^S is fixed and all workers are available to be hired in any period. Also, the labour market is characterised 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 set-up (see Section 3.3 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 labour demand based on the received orders (capital-good sector), the expected demand (consumption-good sector), and the expected labour productivity level. 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 labour 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, 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 are 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 a learning-by-doing process when employed and a gradual deterioration of skills while unemployed, 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 labour market, workers retire and are replaced by younger ones,[8] whose skills are equivalent to the current minimum level in the incumbent firms.

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

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}, the expected 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 expected vintage productivity. The worker effective production depends, yet, on its utilization in the production process, according to the firms desired production level $Q_{j,t}^d$. 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 Dosi et al., 2010 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.

3.3 Alternative labour-market policy regimes

We employ the model described above to study two alternative policy regimes, which we call *Fordist* (our baseline) and *Competitive*.[9] The policy regimes are telegraphically sketched in Table 1.

Under the *Fordist regime*, wages are insensitive to the labour market conditions and indexed to the productivity gains of the firms. 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. Labour 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 and the decentralised labour 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 balance between skills and wages, using a simple payback comparison rule. The Competitive regime is also characterized by different labour institutions: minimum wage is only partially indexed to productivity and unemployment benefits – and the associated taxes on profits – are relatively lower.

	Fordist (baseline)	Competitive
Wage sensitivity to unemployment	low (rigid)	high (flexible)
Workers search activity	unemployed only	unemployed and employed
Labour 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

Table 1: Main characteristics of tested policy regimes.

The simulation exercises in Section 5 are configured so that there is a regime transition at a certain time step, capturing a set of labour-market "structural reforms". This institutional shock is

[9]The two regimes roughly capture two alternative *wage-labour nexus* in the words of the *Regulation Theory* (see, within a vast literature, Boyer and Saillard, 2005 and Amable, 2003).

meant to spur flexibility on the relations among agents in the labour market and implies that the social compromise embodied in the Fordist regime is replace 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, 2017). In addition, the labour-enhanced version of the model (Dosi et al., 2016, 2017), which explicitly accounts for microeconomic firm-worker interactions, has already proved to be able to robustly reproduce most of the labour market macro empirical regularities.[10]

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)

Table 2: Correlation structure with respect to GDP on selected variables. All results significant at 5% level. MC standard errors in parentheses. Non-rate series are Baxter-King bandpass-filtered (6,32,12).

The extensions to the K+S model proposed here added some new empirical regularities matched by the model. First, the new labour force learning dynamics dynamics produce fat-tailed skills (worker level) and productivity (firm level) distributions, consistent with the empirical evidence suggesting the presence of both firm- and worker-specific heterogeneity. Second, the improved entry dynamics increased the number of the model variables that match the usual cross-correlation/lag structure among aggregated macro indicators. As shown in Table 2, net entry is pro-cyclical and lagging with respect to GDP, coherently with the specified state-dependent entry dynamics, but also counter-cyclical and leading on GDP. Time series correlation structure of some financial variables also added new insights. While the Fordist regime presents the same lag structure already revealed in Dosi et al. (2013), at least in terms of debt pro-cyclicality, in the Competitive regime debt is just mildly pro-cyclical and more lagged. In fact, credit (debt) is now also a slightly counter-cyclical leading indicator to GDP, as suggested by empirical data.

5 At the roots of hysteresis

Let us study the emergence of hysteresis in our model, addressing the possible causes and discussing the consequences for the economic dynamics. We will first study *inter-regime* long-run hysteresis (cf. Figure 1), also testing the Blanchard-Summers hypothesis (Section 5.1). We will then analyse the emergence of *intra-regime* transient hysteresis (Section 5.2).

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

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 labour market, leaving however *untouched the technological fundamentals*. In our policy typology, the reforms are supposed to move the labour market regime from a Fordist to a Competitve set-up (see Section 3.3 above). In that, we are implicitly testing the insider-outsider hypothesis of hysteresis proposed by Blanchard and Summers (1987). The normative implication of such hypothesis is the advocacy of a more flexible labour market, where unions have lower bargaining power in the wage formation process, with the aim of making wages more respondent to unemployment conditions. In our model, the transition from a Fordist toward a Competitive type of labour 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.[11]

In Figure 2, we report the time series of the main macroeconomic variables in the two regimes.[12] The institutional shock occurs at time $t = 100$ (the vertical dotted line). The widening GDP gap between the two regimes, as presented in Figure 2.a, shows how the structural reforms determine not only *super hysteresis* (i.e., a permanently lower growth rate of the GDP), but even a form of *asymptotic* hysteresis, whereby the effects propagate in the very long-run (see also Dosi et al., 2017, 2016). The actual level of the long-run capacity utilization increases from the 85% to 90% after the introduction of the Competitive regime (cf. Figure 2.b), hinting at a process of underinvestment due to the worsened business opportunities for firms. In the Competitive regime, as a result of the depressed wage dynamics, increased GDP volatility, and their effect on the aggregate demand, firms reduce the average expansionary investments, which depend on the difference between (demand-led) desired and installed production capacity, pushing down the number of machines ordered from the capital-good sector. As a result, firms decrease the gap between the effective production and the potential capacity, which leads to a cyclical surge in the capacity utilization, that is, during good times firms utilize almost all the available capital to produce goods. The 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 2.c 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 sustained lower trajectory (Figure 2.d) and the average level of workers skills is significantly reduced (Figure 2.e). Finally, the trend of the net entry[13] of firms in the market is more turbulent after the reforms, indicating a higher level of volatility in credit conditions (Figure 2.f).[14]

The different performance of the two regimes is quantitatively summarised in Table 3, which presents the averages and the ratios between selected variables of the two set-ups and also 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 invariant between the two regime specifications, the significant effects on the productivity, innovation and imitation rates are entirely caused by the institutional shock.[15]

[11] 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, if might have some economic roots, did occur at the socio-political level. For this reason, we perform a comparative static analysis, mimicking a quasi-natural experiment with a "treated" and "control" group.

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

[13] The use of the two-sided H-P filter produces the diverging patterns of the two curves before time $t = 100$.

[14] Entry decision in the model is also driven by the average financial conditions of the firms in each sector.

[15] In accordance with the behavioural rules set in the model (cf. Dosi et al., 2010 and Dosi et al., 2017), the dynamics of innovation, of imitation, of new machines introduction and, consequently, of the firms productivity growth is directly

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 std. deviation	0.0618	0.1710	2.7672	0.000

Table 3: Comparison between policy regimes, selected time series. 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.

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,[16] which, in turn, leads to the emergence of Keynesian unemployment due to the contraction of aggregate demand and the slowdown on the skills accumulation and on the productivity growth. Figure 3 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 3.a, b and 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.[17] In the same direction, the results in the second row of Figure 3 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.[18] According to the adopted entry rule, the financial conditions of incumbents do affect the decision to enter in the market. In the presence of overall improving financial state of firms, e.g., whenever there is a growing sectoral difference between net worth (liquid assets) and debt, firms are more inclined to enter. However, note that 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 phenomena, the more pronounced leverage cycle and the tighter availability of credit, have been documented by Ng and Wright (2013) as *emerging* business cycle stylised facts from the last three recessions (1990, 2001, 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 hire (fire) first workers with higher (lower) skills.[19]

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.

[16] The real wages growth rates are 1.47% and 1.35% per period, respectively.

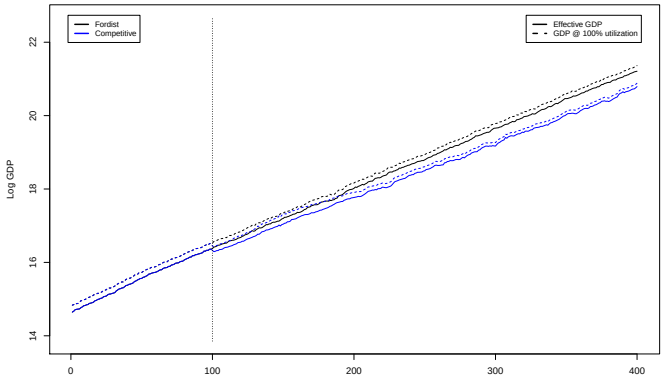
[17] See Dosi et al., 2010 for details on the innovation process.

[18] The diverging trend before time $t = 100$ is due to the two-sided H-P filter we employ to detrend the series.

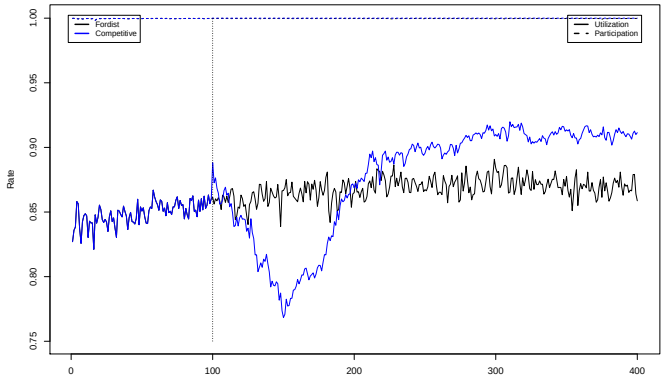
[19] This is a necessary consequence of the firms unilaterally decided and homogeneously applied wage adjustments, so skills are the only heterogeneous metric among workers in a Fordist firm.

Figure 2: Macroeconomic dynamics in alternative policy regimes.
Lines represent 50 MC runs time step averages (Fordist: black | Competitive: blue).

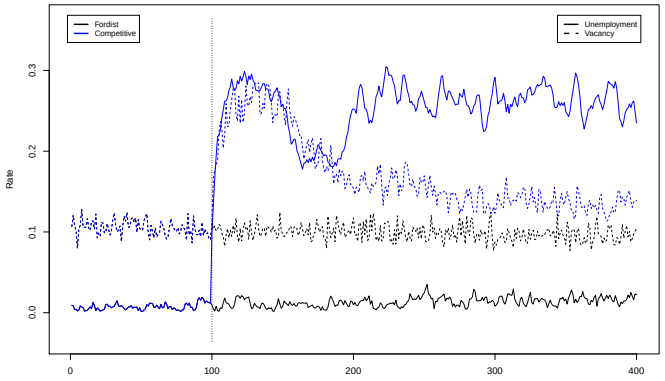
(a) Actual and full capacity GDP



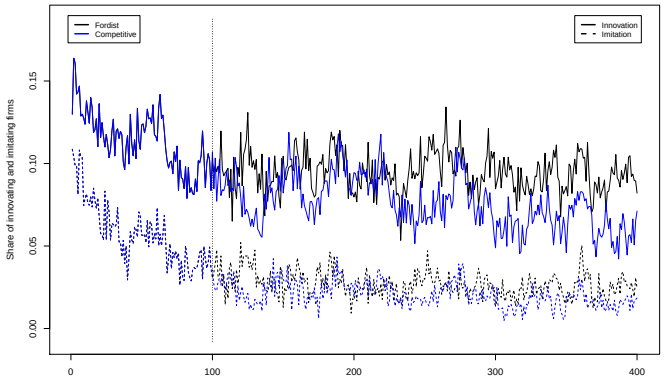
(b) Capacity utilization



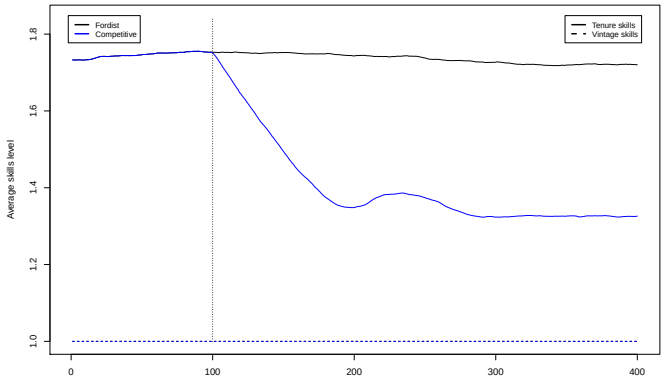
(c) Unemployment and vacancy rates



(d) Innovation and imitation rates



(e) Average worker skills



(f) Net entry of firms (HP-filtered trend)

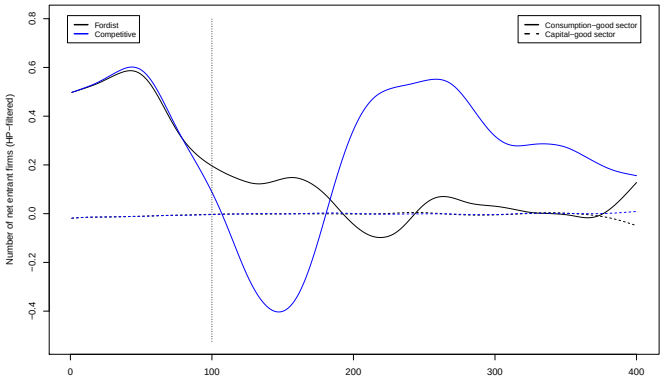
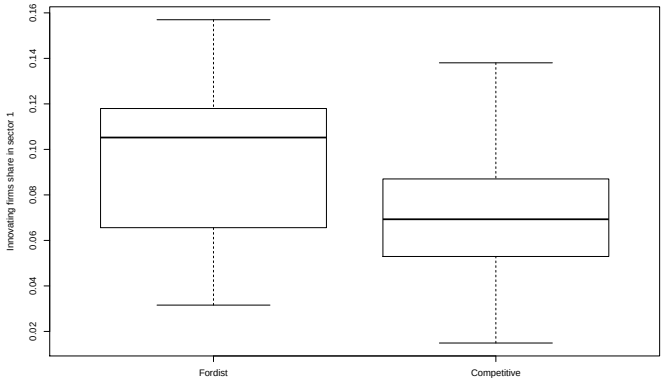
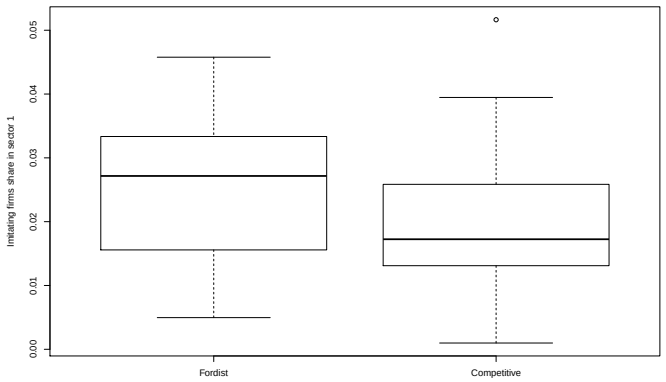


Figure 3: Performance comparison between policy regimes (Fordist: left | Competitive: right).
Summary statistics for 50 MC runs in period $[200, 400]$ (excluding warm-up). Bar: median | box: 2nd-3rd quartile | whiskers: max-min | dots: outliers.

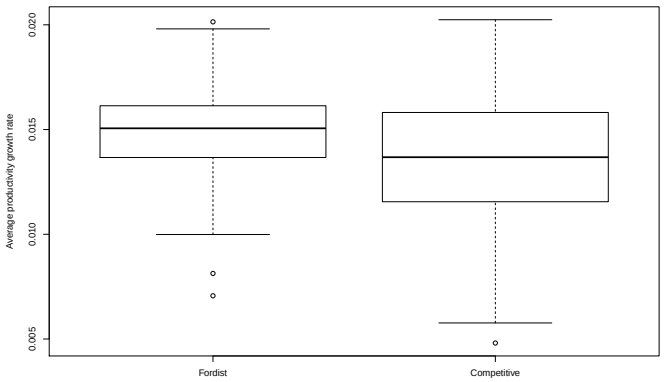
(a) Innovation rate



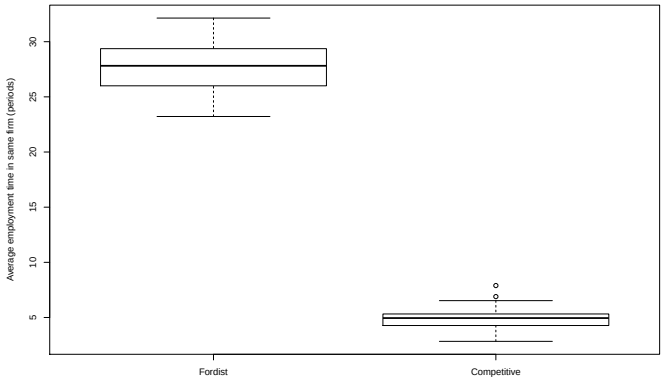
(b) Imitation rate



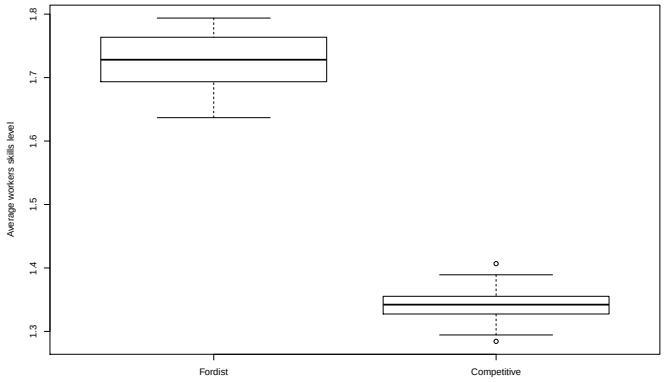
(c) Productivity growth rate



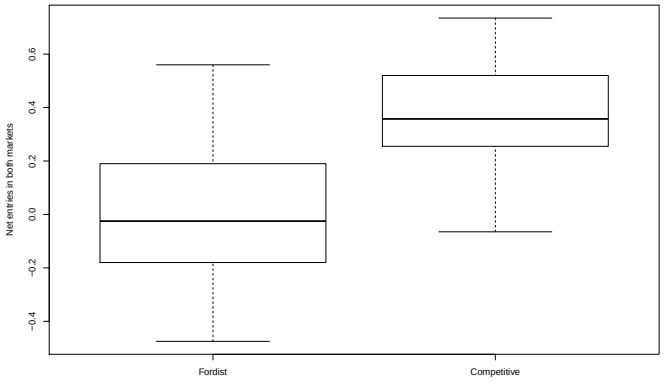
(d) Worker tenure



(e) Worker skills



(f) Net entry of firms



Conversely, in the Competitive case, firms use the skills-to-wage "payback" ratio as a decision guide to preferentially hire (fire) workers with superior (inferior) ratios. Such a behaviour has a negative impact on the aggregate skills 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 labour demand, which induces more unemployment, characterising 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 2 show the significant level of correlation between the business cycle and the net entry of firms in the market.

To sum up, our simulation experiments on the K+S model – extended with endogenous firms entry and workers skills accumulation/deterioration – 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. However, our results seem to provide a more consistent explanation for its *main* causes and also bring a critical warning. The model suggests that structural reforms aimed at increasing the flexibility in the labour market, may well spur even more hysteresis instead of reducing it. Considering 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 unifying 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 4, 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 4 illustrates the number of periods (grey area) necessary to put the economy back to the pre-crisis growth trend (dashed line) in typical simulation runs.[20] The analysis is inspired by (Blanchard et al., 2015) and simply performs an extrapolation of the long-run GDP trend to detect the recovery from crises under the 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 to peak GDP trends (dashed lines).

Table 5 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. In order 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 two times deeper than in the Fordist scenario. The accumulated GDP losses comparison leads to a similar conclusion.

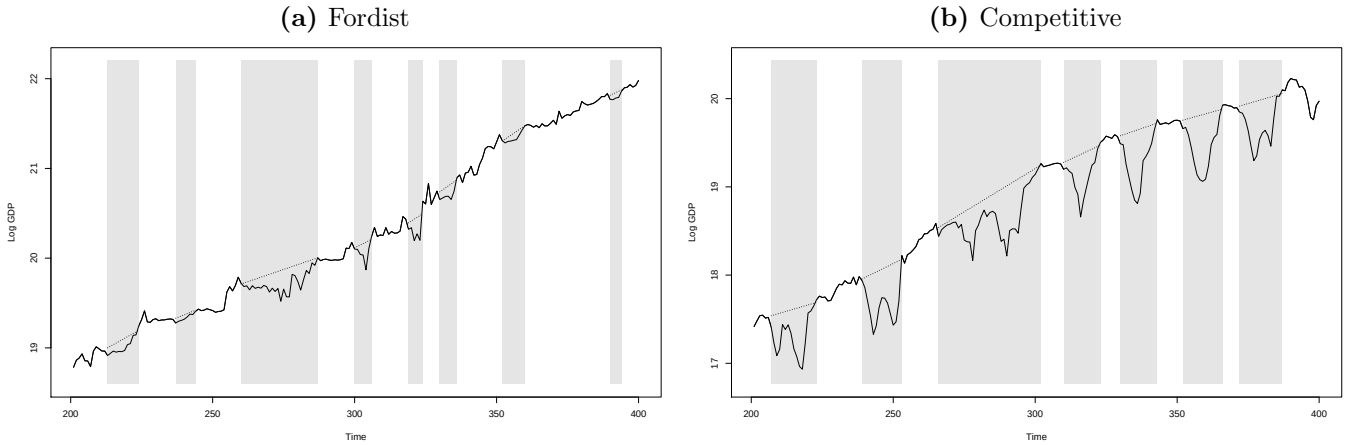
In Table 6, we report a set of statistical tests to detect unit-roots/stationarity (Augmented

[20] 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, as the output of an H-P filter at the period just before the crisis. The crisis is considered recovered when the GDP reaches back the pre-crisis trend level.

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	Brock-Dechert-Scheinkman 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

Table 4: Selected tests to evaluate hysteretic properties in times series.

Figure 4: GDP recovery after crises.
Typical simulation runs. Dashed line: pre-crisis trends | Gray boxes: recovery periods.



Dickey-Fuller/ADF, Phillips-Perron/PP, and Kwiatkowski-Phillips-Schmidt-Shin/KPSS tests), i.i.d./nonlinearity (Brock-Dechert-Scheinkman/BDS test), and ergodicity (Kolmogorov-Smirnov/KS and Wald-Wolfowitz/WW tests).[21] 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 6 for the definition of H_0 in each case).

	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)

Table 5: Comparison between policy regimes: GDP and unemployment time recovery.
Averages for 50 MC runs in period $[200, 400]$ (excluding warm-up), MC standard errors in parentheses.

The results of the tests suggest that GDP, productivity and wage growth rates more frequently exhibit stationary (no unit-roots) behaviour in both regimes. More borderline, the unemployment rate time series seems to be more commonly stationary among simulation runs in the Fordist regime, while more likely non-stationary in the Competitive case. The nonlinearity test indicates a more nuanced situation: the unemployment series is the one more frequently nonlinear (not i.i.d.), particularly in the Competitive regime, while the wage growth rates series are more likely linear (i.i.d.). Finally, the less powerful KS test cannot reject ergodicity for the majority of run pairs tested, while WW indicates the non-ergodicity of all series.

There are a few take-home messages from the tests. The first is that mixed results, e.g., on

[21] We report alternative tests for each property because of possible test lack of power in some circumstances.

ergodicity or stationarity, militate in favour 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, non-linear structure, are quite encouraging despite the limited length of the sample paths.[22]

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

Table 6: Comparison between policy regimes: statistical tests for detecting hysteresis.
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 (Augmented Dickey-Fuller)/PP (Phillips-Perron) H_0: non-stationary | KPSS (Kwiatkowski-Phillips-Schmidt-Shin) H_0: stationary | BDS (Brock-Dechert-Scheinkman) H_0: i.i.d., KS (Kolmogorov-Smirnov)/WW (Wald-Wolfowitz) H_0: ergodic.

We performed a global sensitivity analysis (SA) to explore the effects of alternative model parametrisations and to gain further insights on the robustness of our exercises on institutional shocks.[23] Out of the 57 parameters and initial conditions in the K+S model, we reduce the relevant parametric dimensionality to 29, by means of an Elementary Effect screening procedure which allowed discarding from the analysis the parameters which do not significantly affect the selected model outputs.[24] In order to understand the effect of each of the 29 parameters over the selected metrics, we perform a Sobol decomposition.[25] Because of the relatively high computational costs to produce the decomposition using the original model, a simplified version of it – a meta-model – was build using the Kriging method and employed for the Sobol SA.[26] 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).[27]

The main indicator used for the SA is the accumulated GDP losses during the crises' recovery periods, as defined above. It seems a sensible choice, as it conveys information about both the

[22]The choice of the adequate time window length is quite relevant when analysing 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. For comparability with empirical data, to check for the intra-regime hysteresis we restricted the time span to 50 runs (12.5 years), 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: in the very long run most real economic series look stationary and ergodic.

[23]For technical details on the global sensitivity analysis methodology, see Dosi et al. (2016).

[24]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 (nonlinear/non-additive) effects of parameters on the model results (Morris, 1991, Saltelli et al., 2008).

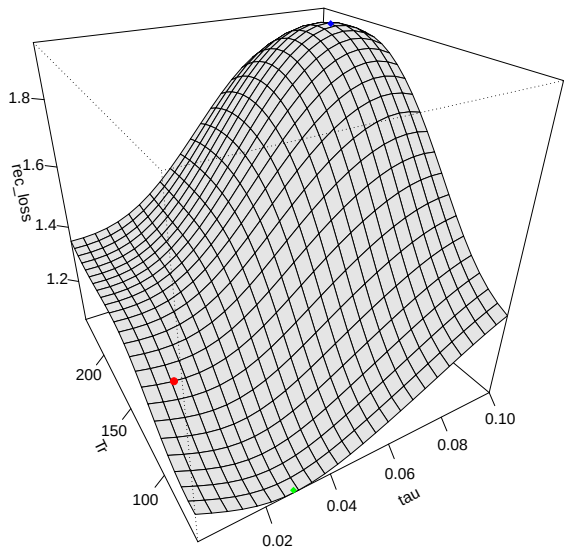
[25]The Sobol decomposition is a variance-based, global SA method consisting in the decomposition of the variance of the chosen model output into fractions according to the variances of the parameters selected for analysis, better dealing with nonlinearities and non-additive interactions than traditional 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).

[26]In summary, 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, non-linear computer simulation models (Rasmussen and Williams, 2006, Salle and Yildizoglu, 2014).

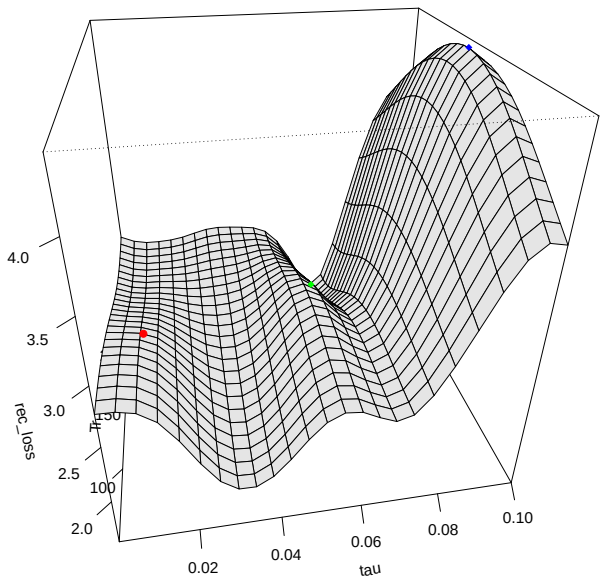
[27]Due to space restrictions we cannot present all the tests statistics here but they can be requested to the authors.

Figure 5: Global sensitivity analysis: response surfaces.
Surfaces modelled using the fitted Kriging meta-model. z axis: recovery losses (rec_loss).
Red dot: calibration settings | Markers: maximum (blue) and minimum (green) predicted crises losses.

(a) Fordist



(b) Competitive



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 no initial condition), namely 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), and the minimum capital ratio (Φ_1) and the expected capacity utilization (u) of the consumption-good entrants. 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.

Figure 5.a and 5.b presents an exploration of the model response surface, using the Kriging meta-model, for the two critical skills-related parameters. The rugged surfaces, in particular in the Competitive regime, clearly indicate the nonlinear nature of the system, in tune with the requirements for hysteretic behaviours. The sensitivity analysis of the model 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 5 parameters account for 95% of the variation of the GDP crises losses in the model for the two scenarios. This ensures that the comparisons between policy regimes presented above are *not* influenced by specific configuration settings. As can be seen in Figure 5, the Competitive regime tends to produce significant higher GDP crises losses irrespective of the model set-up (notice that the peak losses in plot (a), the blue dot, are at a lower z axis level than the deepest valley in plot (b), the green dot). 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 rebuilt the firm skills destroyed by a crisis, and to be back to the pre-crisis level.

All in all, the statistical tests results indicate that model has a rather frequent tendency to produce runs which 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

A revival of the debate on hysteresis has emerged in the aftermath of the Great Recession. Together, the evidence forced revisiting the standard approach of modelling unit-root processes as good candidates to explain the persistent deviations from the pre-crisis trends. Not only the level trends of GDP and unemployment, but even the growth rates in many countries are still persistently bellow the pre-2008 figures, leading to the importance of a stronger notion of hysteresis.

As an alternative, an expanding tradition of scholars have been discussing 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 deviation from stable growth trajectories. Nested into the latter literature, here we have presented an ABM which intertwines a Schumpeterian engine of growth and a Keynesian generation of demand, declined under two institutional labour-market variants, labelled as Fordist and Competitive regimes. The transition from the Fordist to the Competitive regime captured "structural reforms" aimed at increasing labour market flexibility.

The model is able to generically exhibits 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. In a more specific instance, the model fails in providing support to the Blanchard and Summers (1986) insider-outsider hypothesis, according to which more flexible labour relations might reduce hysteresis. On the contrary, the model suggests that both numerical and wage flexibility are quite prone to increase the hysteretic properties of the macroeconomic system.

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