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The political economy of complex evolving systems: the case of declining unionization and rising inequalities

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The political economy of complex evolving systems: the case of declining unionization and rising inequalities*

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Abstract

This chapter presents an application of the multi-sector labour augmented K+S agent-based model to two contemporary challenges in political economy, namely declining unionization and rising inequality, with reference to

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medium-term evidence in the US. What has been the effect of declining unionization? The model proves to be a promising tool in order to confront different scenarios emerging out from the interaction of an endogenous dynamic competition between union and non-union firms, the latter arriving at a specific time. The arrival of non-union firms induces direct first-order effects, as rising inequality at the workplace and macro level, but also, indirectly, second order effects, as lower rates of labour absorption, and demand patterns skewed toward luxury consumption goods for the wealthy. In that, complexity economics proves to be a promising avenue to incorporate and confront the grand challenges of contemporary capitalism.

JEL classification: J51, E02, E24, C63

Keywords: Complexity, Capitalism, Socio-economic structure, Macro-evolutionary agent-based model.

1 Introduction

This chapter discusses the link between political economy and agent-based macro models, drawing upon the multi-sector (Dosi et al., 2022) labour-augmented K+S family of models (Dosi et al., 2017, 2018, 2020). Capitalist forms of socio-economic organization have always been characterized by ubiquitous heterogeneity among economic agents, conflicts among social groups, and coordination hurdles. Consequently, the system has always been generating structural imbalances, fluctuations, and crises. However, the recent trends are pointing at an increasing fragility of the system, together with deepening inequalities and the erosion of those forms of public intervention and institutions. In the post WWII, the latter had guaranteed relatively stable patterns of income distribution, the provision of both public goods and relatively universal access to social welfare. Indeed, the relationship between the state and the economy has radically changed, with the former that has increasingly given up its role of socio-economic coordinator and basically taken up that of protector of corporate interests.

How can economists analyse, model and identify such alternative modes of socio-economic organization and their properties? The dominant macroeconomic

theory is bound to be totally mute on the subject. The litmus test has been the 2008 crisis whose very possibility was ruled out by construction, given its solipsistic agents and the commitment to equilibrium (Colander et al., 2008; Krugman, 2011). It is even less able to address the political-economy issues related to changes in the broad institutional set-up, mostly restricted to economic institutions rewarding innovation efforts (Acemoglu and Robinson, 2013). This is further demonstrated in the other chapters of this section (Bednar, 2024; Beinhocker and Bednar, 2024).

Agent-based models (ABMs), built on the convergence between evolutionary and complexity paradigms (Dosi and Roventini, 2019; Dosi, 2023), have been in the last three decades an important source of scientific knowledge to advance our understanding of the dynamics of capitalism. The Santa Fe Institute series "The Economy as a Complex Evolving System", now in its fourth volume, is a testimony of this process. Evolutionary ABMs have proved to match an impressive ensemble of stylized facts, that is, basic statistical regularities – ranging from the micro-level distributions of firm sizes and growth rates, the pattern of evolution of industries, all the way to macroeconomic fluctuations and crises. In addition, they represent a powerful tool to scenario analysis. Granted these results, we are just in the middle of a multipronged effort to understand and also formalize some fundamental *general properties* of the "anatomy and physiology" of the capitalist socio-economic fabric.

The dynamics of the socio-economic fabric is subject to profound *phase transitions* shaped by the co-evolution between technologies, institutions and economic processes. This includes also transitions toward self-cannibalization (Fraser, 2023), and the self-destruction of the system. Indeed, such dynamics is the domain of analysis that we call the *political economy* of agent-based macro models. This, we suggest, is the next frontier which ABMs are just beginning to tackle. Those models are powerful policy laboratories (Dosi et al., 2020), in that they are consistent simplified worlds, wherein experiments with different policy measures and institutional set-ups can be configured. As such, they can be precious instruments for the exploration of alternative political economy scenarios. This goes well beyond counterfactual exercises concerning the marginal impact, ceteris paribus, of sin-

gle policies upon specific variables, say, the rate of growth or the overall level of functional inequality. Rather, the exploration of different scenarios regards also the painstaking search of *combinations of institutions and policies* able to reverse the current trends toward dramatically increasing inequalities in the distribution of income and power, and, relatedly, toward the social and environmental catastrophe.

In this chapter we address two fundamental challenges in contemporary capitalism, namely, the decline in unionization rate, and the rise in income inequality. What have been the micro and macro-level effects of the declining unionization rate? The historical counterpart of such phenomena, which we use to highlight the empirical plausibility of the analysis, is the US experience. There, one observes the repeated defeats of unions in disputes, and the growing anti-union legislation, including right-to-work (RTW) laws, disfavouring union firms and paving the way for anti-labour practices. In the following, we present an application of the multi-sector, labour-augmented K+S agent-based model addressing the declining unionization and rising inequality. The model proves to be an important tool to confront different scenarios emerging out of the endogenous dynamic competition between union and non-union firms. The arrival of the latter induces direct first-order effects, as rising inequality at both the workplace and the macro level. Indirectly, it drives second-order effects, as lower rates of employment absorption, and demand patterns skewed toward luxury consumption goods for the wealthy.

In the following, drawing upon Dosi et al. (2022) and Dosi et al. (2021), we first discuss the two challenges of political economy we would like to explore. We then move to the agent-based model application, presenting our model properties and results. We conclude the chapter by discussing our findings and some avenues for future research.

2 Two grand challenges for contemporary political economy: rising inequality and declining union power

The rise of inequality is certainly one of the predominant trend documented in contemporary capitalism. Inequality has increased (i) in wage dispersion among sim-

ilar occupations located in different establishments (Barth et al., 2016), (ii) across occupations in the same companies, between CEOs and the rest of the workforce (Gabaix and Landier, 2008), (iii) in terms of functional income inequality (Dosi and Virgillito, 2019), (iv) in terms of personal income or wealth (Piketty, 2015), and (v) within and across countries (Milanovic, 2024). Its multidimensional effects have propagated from economic to political spheres (Stiglitz, 2015), from definition of property rights to access to public goods (Dosi et al., 2024).

The extant literature has mostly attributed individual wage inequality to the skill- and routine-biased nature of technological change (Autor and Dorn, 2013). According to such research stream, the determination of wage and the ensuing origin of inequality are a market-based issue. Therefore, the dynamics of labour remuneration is mainly due to technology-related causes, driven by changes in the elasticity of substitution among inputs, yielding "biases" in the demand for different types of jobs. In turn, such biases are matched by the 'wrong' educational attainments, and the corresponding skill mismatch, with a rising demand for college-educated workers (Tinbergen, 1974; Katz and Murphy, 1992). Under that perspective, the *skill-bias* interpretation is deemed as the dominant explanation for inequality. It has been gradually adopted to analyse job tasks and technological-based factors according to the *task-biased* or *routine-biased* technical change approach (Acemoglu and Autor, 2011). In practice, this trend has been primarily attributed to the rise in computer adoption, until the Great Recession, or, more recently, to a general "robotization age" (Restrepo, 2023). In a nutshell, technological-driven factors are seen as responsible for a modification in the composition of occupational structure, leading to the disappearance of intermediary occupations, and also for the polarization in wages. More recently, AI, with its growing diffusion, has been also taken on board (Acemoglu et al., 2022).

However, growing evidence is questioning the technology-driven origin of inequality (Dosi et al., 2022; Mishel, 2022; Cetrulo et al., 2024). The need of accounting for deeper and persistent non-technological drivers has refocused the attention of scholars towards other possible factors that could impact on the determination of wages, and inequality. This certainly requires a departure from simplis-

tic neoclassical premises, based on (perfectly) competitive labour markets able to (fairly) reward individuals for their skills and productivity. Alternative candidates to explain wage levels, inequality, and the associated dynamics, must consider the socio-institutional dimensions embedded into the occupational class structure (Penissat et al., 2020; Goedemé et al., 2021), the rise of care economy (Dwyer, 2013; Folbre, 2021), and the weakening of labour market institutions (Stansbury and Summers, 2020).

Increasing wage disparities are usually linked with the widespread decline in the labour share of income. A declining share is not only a signal of wage compression and functional inequality but, behind that, the reorganization of capitalism in favour of managerial-shareholder power. Such rise in power has been a force pushing managerial remuneration, including in terms of shares and stock options, up to the point, documented by Bivens and Kandra (2022), of a rise of almost 400 times in the CEO/average worker compensation ratio in the listed companies present in the Compustat dataset. Such an increase represents a dramatic process of income redistribution that certainly cannot be ascribed to the relative worker productivities.

The decline of labour share has come together with, or because of, a reduction of the *bargaining power* of workers. Under non-decreasing returns and asymmetric power relations between employers and employees, the distribution of income might well be the outcome of a negotiation process between firms and workers, possibly represented by unions and mediated by labour market institutions. Workers, whenever protected by strong unions and pro-labour legislation, are likely better able to negotiate wage increases in line with productivity gains, helping to maintain a stable labour share.

Empirically, there is a growing consensus on the role of labour market institutions in affecting the share dynamics through the bargaining power channel. Several studies have found that factors such as strike activity, collective bargaining arrangements, minimum wages, and union density, affect the labour share (Kristal, 2010; Bentolila and Saint-Paul, 2003; Argitis and Pitelis, 2001). In particular, union density – the percentage of unionized workers within a given worker population

– has been shown to have a positive effect on the labour share at the country level (Guschanski and Onaran, 2021; Stockhammer, 2013a; Bengtsson, 2014; Stockhammer, 2013b; Jaumotte and Osorio Buitron, 2020). In addition, the evidence (Dao et al., 2020; Dimova, 2019) suggests that unions may have different effects on the wage-setting process for dissimilar skill groups, protecting in particular low-skilled workers, thus reducing wage inequality. A piece of long-run historical evidence on the positive effects of unionization for taming inequality is in Farber et al. (2021).

Historically, the rise of union power in the US has been described as a spurt dynamics (Freeman, 1998), with a rapid increase from the thirties up to the mid fifties, reaching a peak value of 36%. Two laws were important in that phase. The first was the National Labor Relations Act (NLRA) in 1935, also known as the Wagner Act, providing an institutional framework for union workplaces. It ensured the right to unionize, including collective bargaining, the right to strike and the institution of a federal commission, the National Labor Relations Board, responsible to prosecute unfair labour practices. With the approval of this law, the initial phase of the spurt started (see Figure 1). A subsequent anti-labor policy, the Taft-Hartley Act in 1947, was introduced to limit the space of action of unions, and also to stop the ascending unionization. The act allowed each state to pass right-to-work (RTW) laws, that exempt workers in unionized plants to pay fees even if they benefit from the union activity (Fortin et al., 2023). Historically, Southern and Midwestern states have adopted RTW laws, and that has been associated with lower unionization rates. More recent legislation, post-2010 in five states around the Great Lakes, have produced an acceleration in deunionization rates, as compared to the previous situation, with stronger declines in more unionized sectors (Shierholz et al., 2024; Fortin et al., 2023). Figure 1 shows the dynamics of union density in the US and marks the timing of different laws, accounting for the rise and decline in unionization.

More generally, the decline in union membership, a socio-institutional trend since the nineteen seventies, has been found to account for the rising wage inequalities. While unions have always been considered as an institution compressing

wage inequalities for union workers, Western and Rosenfeld (2011) also highlight the effects upon wage increases for non-union workers by means of the complementary effect on their wages. The decline in unionization has been linked to two main drivers: structural-economic forces, due to the rise in employment outside historically-cohesive union industries, and institutional forces, due to increasing employer power and anti-union practices. This trend intensified following the US "Reagan moment", with the defeat of air-traffic controllers strike in 1981 as a pivotal symbolic event, and the appointment of the Reagan Labor Board in 1983, as the institutionalization of a new anti-labour role for the board (Farber and Western, 2002; Tope and Jacobs, 2009). Coming to the first group of explanations, Hirsch (2008) shows that much of the decline has been driven by within-industry dynamics, due to a progressive increase in the share of non-union firms. Similar evidence is presented in Farber and Western (2002). Market competition between union and non-union firms has favoured the latter: unionized firms, paying more equal and higher wages, face progressively lower-cost competitors, and so they are not able to pass the higher costs to prices, and eventually are forced to leave the market.

Needless to say, one is still far from accounting for all such institutional richness into any agent-based model. However, in the following, we represent an instantiation of such phenomena, illustrating the endogenous co-evolution between deunionization and market-driven competitive forces, with non-union firms entering into the market and competing with incumbent union ones. While the end outcome of such dynamics is fully endogenous, the specific arrival time of non-union firms can be interpreted as the exogenous introduction of a RTW-type law, favouring deunionization (Fortin et al., 2023; Shierholz et al., 2024). This way, the model can account for both structural and institutional drivers. In addition, considering that unionization is an industry-specific attribute, the effects of the introduction of a RTW law is expected to be industry-specific as well. Notably, Fortin et al. (2023) show that the introduction of RTW laws have induced faster decline in unionization, notably in previously high-unionization industries.

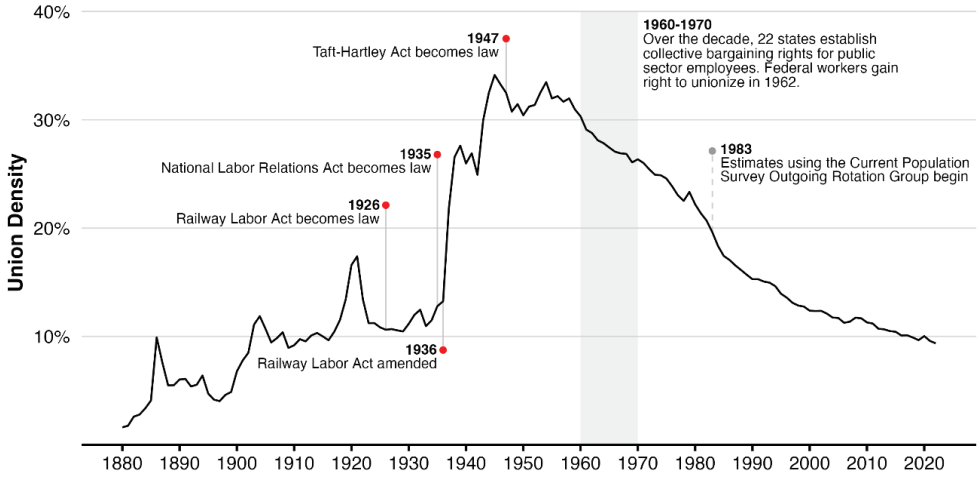


Figure 1: Union density 1880-2022. Figure 1 in Romero and Whittaker (2023).

3 The multi-sector K+S model facing political economy

We present a *general-disequilibrium*, stock-flow-consistent, agent-based model, populated by heterogeneous workers, firms, and banks which behave according to heuristic rules.[1]

In a nutshell, the multi-sector, labour-augmented Schumpeter Meeting Keynes model (K+S) is meant to analyse the long-term pattern of labour demand under the fundamental duality of technical change. Therefore, the model endogenously deals with two contradictory forces: the labour shedding effect of efficiency-enhancing *process innovation*, and the job-creating outcome of *product innovation*. The ABM perspective allows tackling such a duality under conditions of disequilibrium, thus avoiding any ex-ante commitment to the assumption that the two effects will compensate (or not) in the aggregate. Process innovation is represented by the arrival of new techniques of production, embedded in new capital-goods, that are employed to enable product innovations, which diffuse across producers and among users. Product innovation in final goods here is modelled by means of the emergence of new industries.

The model economy is composed by five populations of heterogeneous agents,

[1]The section draws upon Dosi et al. (2022), to which the reader is referred for all technical details.

namely, L^S workers/consumers, F_t^1 capital-good firms, F_t^2 consumption-good industries with $F_{h,t}^2$ firms in each, and B banks, plus the central bank and the government.[2] The basic structure of the model is depicted in Figure 2.

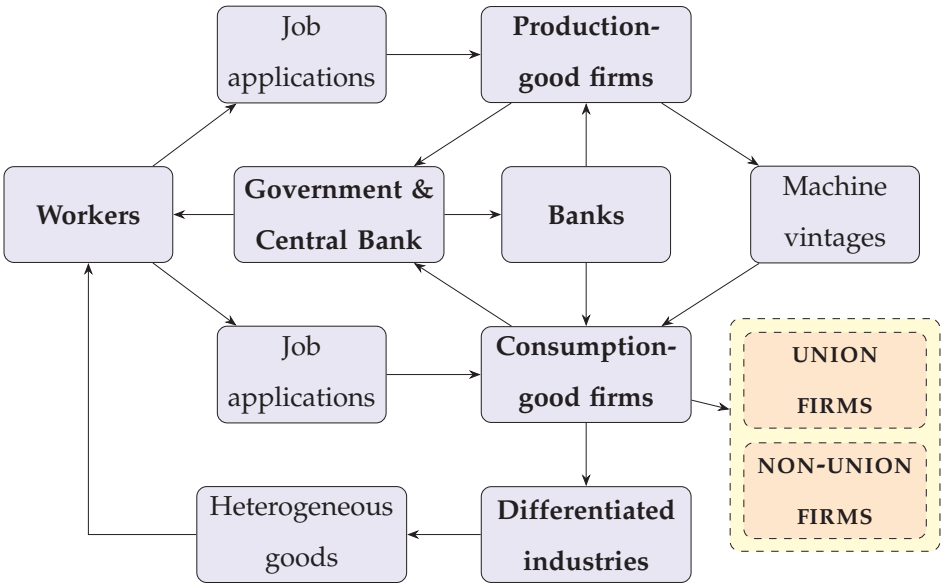


Figure 2: The model overall structure. Text in bold style represent the model's agents.

Consumer-workers demand goods in a hierarchical order starting from basic and moving to luxury ones. Consumers split their income between basic- and luxury-good budgets, entirely allocating it to basic goods up to a given threshold, corresponding to the median of income distribution, and the excess, if any, to luxury consumption. The budget for (divisible) basic goods is (tentatively) spent every period, and split among basic-good industries according to the respective products attributes (price, quality, novelty and complexity). Luxury goods, which are not divisible, are acquired whenever three conditions are met: (i) a minimum period from last acquisition passed, (ii) at least one not-recently-bought good is obtainable, and (iii) the available luxury budget (current plus accumulated) is enough to buy at least one unit of the chosen good. If these conditions are not met, the

[2]Subscript t stands for (discrete) time $t = 1, 2, ..., T$. Agent-specific variables are denoted by subscript h, in case of industries, i, for capital-good firms, j, for consumption-good firms, k, for banks, and ℓ, for workers.

available luxury budget is saved for the next period. So, the consumption bundle is comprised by a set of heterogeneous basic goods, each one supplied by a different industry and firm, plus possibly one or more units of a single luxury good. If total supply is insufficient to satisfy the resulting demands for basic and luxury goods, the excess is saved in banks, and turns into additional consumption demand in the next period(s).

Workers consume part of their income, and save the rest for acquiring more expensive luxury goods, or to smooth consumption in case of unemployment. On top of wages, paid to all employees, there is a profit-sharing mechanism which allows firms with above-average profits to distribute bonuses as a fixed share of current wages. The government enforces a minimum wage indexed to the aggregate productivity of the economy, and pays a fraction of the average wage to the unemployed. Workers do not take credit for consumption, so all income comes from wage, bonus, or unemployment benefit.

The labour market is modelled as a fully decentralized, search-and-hiring process between workers and firms.[3] The aggregate supply of labour is fixed, and all workers are available to be hired in any period. When unemployed, workers submit a certain number of job applications to a random subset of firms. Employed workers may apply or not for better positions. Larger firms have a proportionally higher probability of receiving job applications, which are organized in separated, firm-specific application queues. The labour market is also characterized by imperfect information as firms only observe workers' skills and wage requests on their own queues, and workers are aware only of the wage offers they may receive from firms where they applied for a job.

Firms, on the grounds of machine orders received, of the expected consumer demand, and the current labour productivity levels, decide whether to (i) hire new workers, (ii) fire part of the existing ones, or (iii) keep the current labour force. Each hiring firm defines a unique wage offer for the best applicants, based on firm- and economy-wide productivities. Workers select the best wage offer they get from firms to which they submitted applications, if any. When already employed they

[3]For simplicity, banks, the central bank and the government occupy no workers.

may quit the current job if a better offer is received. There are no further rounds of bargaining between workers and firms in the same period. Thus, firms have no guarantee of filling all the open positions, workers may not find a job even when there are still unfilled ones, and no labour market clearing is ever guaranteed. Moreover, there are no firing or hiring transaction costs.

Capital-good firms invest in R&D and produce heterogeneous machine-tools whose stochastic productivity evolves endogenously over time. Less frequently, new generations of machines are discovered, enabling the emergence of new consumption goods and industries. Downstream consumption-good firms combine machines bought from capital-good firms and labour in order to produce differentiated goods for final consumers. Across industries with heterogeneous products, consumption-good firms compete for consumers' expenditures. Workers search for jobs, and firms hire them according to their individual demand expectations. The banking sector is represented by a fixed number of banks which take deposits and provide interest-paying loans to finance firms' production and investment plans. The central bank manages the monetary policy, imposes regulatory reserves to the banks, and bails out the failing ones. Government levies taxes on firm and bank profits, pays unemployment benefits, imposes a minimum wage, absorbs excess profits and losses from the central bank, and keeps a non-explosive public debt trajectory in the long run.

The capital-good industry is the locus of endogenous innovation in the model. Capital-good firms innovate by developing new machine-embodied techniques or imitate the ones of their competitors in order to produce and sell more productive and cheaper machinery. Innovation is of two types, *incremental* or *radical*. Incremental innovation gradually increases productivity of existing technologies, both on new machine construction and their usage. Radical innovation introduces a new, qualitatively different generation of machines, associated to a new technological paradigm, which is more productive to use but also more expensive to produce and is possibly associated with the arrival of new industry producing "luxury" goods (see below). Machine prices are set using a fixed mark-up over (labour) costs of production.

Consumption-good firms in each industry produce a single, quality-, novelty-, and complexity-differentiated good, employing capital (composed by different "vintages" of machine-tools) and labour, 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 limits, on bank loans. Moreover, they replace non-economical machines according to a payback-period rule. As new capital embeds state-of-the-art technology, the labour productivity of consumption-good firms increases over time according to the mix of (employed) vintages in the capital stocks. Firms choose the capital-good supplier comparing price and productivity of the machines they are aware of. They fix their output prices applying a variable mark-up rule on their (labour) production costs, balancing profit margins and market shares, increasing mark-ups and prices whenever expanding, and vice versa. Imperfect information is also the normal state of the consumption-good markets, so consumers do not instantaneously switch to the most competitive producer. Market shares evolve according to a replicator dynamics: more competitive firms expand, while firms with relatively lower competitiveness levels shrink, or exit the market.

Consumption-good firms group into different industries. Firms in the same industry produce a novelty-homogeneous but quality-differentiated good. New industries introduce novel products, which tend to be preferred by consumers. This introduces a lifecycle dynamics due to inter-industry competition for demand. From the consumer perspective, there are two broad categories of goods: basic (non-durable) and luxury (durable). Luxury-good requires more stages of production resulting in more complex products, and so demanding more labour and capital, resulting in higher prices relative to single-stage basic goods, but increased attractiveness to consumers.

The entry-exit process for industries and firms is entirely endogenous. Industries disappear and firms leave whenever market shares get close to zero or (total) net assets turn negative (bankruptcy). There is a positive probability of a new

luxury-good industry entering the economy after each new machine generation introduction, due to a successful radical innovation in the capital-good sector. New basic-good industries enter randomly, with probability inversely proportional to the number of incumbent basic industries. At the firm level, the (stochastic) number of entrants in an industry depends on the quantity of incumbents and on the prevailing financial conditions.

Firms in an industry may be unionized or not, depending on the current institutional set-up at the moment of entry. Table 1 contrasts the wage-setting and other agents' behaviours for union and non-union cases.

Union firms pay equal wages to all workers and change wages collectively as aggregate and market productivity evolve. They fire employees only when profits become negative. In hiring and firing, union firms try to keep the more skilled employees. Union workers seek alternative jobs less frequently than non-union ones, consistent with the exit-voice trade-off in the labour market (Freeman, 1980).

Conversely, non-union firms set wages according to individual worker skills and labour-market conditions. Wages are set by an asymmetric negotiation process where firms have the last say. There are no hiring/firing protections and unemployed workers must adjust downward wage demand up to the individual "satisficing" level. Employed non-union workers actively search for better paid jobs, and firms frequently fire excess workforce because of shrinking production. Hiring and firing of workers is based on the (individual) wage-to-skill ratio.

AGENT BEHAVIOUR	UNION	NON-UNION
Differentiated wages	no	yes
Wage sensitivity to unemployment	low (rigid)	high (flexible)
Wage indexation to average productivity	full	partial
Labour-firing restrictions	under losses only	none
Worker-hiring rule	higher skills	lower wage-to-skill ratio
Worker-firing rule	lower skills	higher wage-to-skill ratio
Worker new-job search intensity	low	high

Table 1: Differentiated behaviours of union and non-union firms and workers.

To focus on the decline in unionization, we configure the model so that, after an initial phase of just union firms in the market, from time $\hat{t} = 100$,[4] only non-union firms enter the market. From there, both types of firms compete in each industry according to an evolutionary process. After a grace period, at $\hat{t} = 200$ the likelihood of union or non-union firms entering the consumer-good market is proportional to their shares in each industry.

Our primary focus here is on the relationship between deunionization and rising inequality. The validation procedure follows the so-called *output validation* approach (Fagiolo et al., 2019), which is progressively becoming the most adopted empirical validation strategy in agent-based models. According to this approach the model properties at different levels of disaggregation are contrasted with the empirical evidence. That is, the model is judged in terms of its ability to robustly reproduce an ensemble of stylized facts, at different scales of disaggregation. The list of stylized facts and model properties is presented in Table 2, and is in line with the set of micro and macroeconomic stylized facts discussed in Haldane and Turrell (2019). Table 3 shows more details about the list of new properties introduced by the current model, together with references to the associated empirical evidence.

Notice that the proposed validation approach is quite different from the ones based on *moment-matching* or *strict parameter calibration* on single time series, as discussed in chapter 10 of this book (Pangallo and Del Rio Chanona, 2024). The employed procedure avoids both the scaling problems involving direct moment comparison, as well the "trap" of ex post fitting of ex ante strictly calibrated models. Notwithstanding the common belief, estimating the parameters of single time-series independently (one at a time) is epistemologically problematic, an utterly indisciplined exercise potentially compatible with undesirable theoretical settings.[5]

[4] In the following, we present the MC time series excluding a model "warm-up" period, as explained later. Therefore, all time plots refer to relative $\hat{t} = 1, ..., 400$, corresponding to absolute simulated $t = 101, ..., 500$ after the warm-up.

[5] An exemplary case is the common practice of parameter estimation in DSGE models, that although it might prove fit for some empirical moments of specific time series, these are hardly metaphorical models able to explain processes and mechanisms (Bouchaud, 2023).

A commonly cited problem of the output validation approach lies in the weak performance of non-calibrated models for quantitative forecasting. However, ABMs, employed as a representation of evolving complex systems, emerged in economics with the main objective of providing interpretation, rather than precise forecasting.[6]

We next present a battery of model simulation results substantiating our findings concerning explicitly labour relations and labour-market institutions. The model was coded and simulated using the LSD framework (Valente and Pereira, 2023), and the produced simulation results were analysed using the R platform (R Core Team, 2024).[7] The figures presented below are the outcomes of a Monte Carlo (MC) experiment, to properly consider across-run stochastic effects, comprising 100 realizations of 500 discrete time periods ($t = 1, ..., 500$) each.[8] The model is parametrized so that one time period roughly corresponds to one quarter. Initial set-up is kept to a minimum: all industries, firms, and workers start equal, departing from balanced supply and demand, under full utilization.[9] The employed values for the model parameters and initial conditions, including an extensive analysis of the model sensitivity to the chosen values, are available in Dosi et al. (2022). The sensitivity analysis shows that the results below are robust to significant parametric changes.

Starting with Figure 3.a, the spurt dynamics in deunionization is presented for the ensemble of consumption-good industries. The spurt is quite evident as the share of non-union firms after a relative short time interval *endogenously* reaches eighty percent. Notably, non-union firms populate all industries, but they are not

[6] In epistemological terms, long-term, quantitative forecasting of complex systems properties is a "doomed" proposition irrespective of the modelling methodology employed (see, e.g., Arthur, 2015, 2024, in this volume).

[7] Other than these, several auxiliary third-party open-source libraries were used under the respective licence terms. Please refer to `https://github.com/SantannaKS/LSD` for code and licensing details.

[8] Such MC design of experiment was validated to capture the behaviour of most model variables under a significance level of at least 5%, and more typically at 1%.

[9] The objective of this *light-touch* approach is to let the model structure, which induces significant heterogeneity among agents, to find an endogenous initial regime, usually achieved before $t = 100$, the warm-up period. Therefore, results are analysed from $t = 101$ (or $\hat{t} = 1$).

able to dominate the entire market, and a percentage of union firms remain alive, however progressively declining over time. The decline in unionization maps into macro level inequality as shown by the rise in the Gini index from less than 0.15 up to 0.30. Most of the rise is due to the bonus distributed by more profitable firms, as shown by the upper line in Figure 3.b.

Figure 3.c. looks at the process of wage growth across industries. At the industry level, considering inter-firm wage heterogeneity, wage-growth rates under both institutional scenarios present tent-shaped distributions. This is in line with the general and robust empirical evidence on growth rates in landscapes characterized by any type of competition process (Dosi et al., 2017). However, the distribution support widens whenever non-union firms arrive, with more frequent extreme firm-cases at *both* tail sides.

Figure 3.d presents the heterogeneous unionization rate by industry. A U-shaped pattern in terms of incidence of union firms do appear, showing the endogenous emergence of both highly unionized and non-unionized industries in the model. More mixed degrees of unionization across industries are less probable (note the log vertical scale), but still possible scenarios. Accordingly, the prevalence of union firms deeply affects the wage dispersion across firms and industries. Different wage-distribution patterns in the unionized vs. mixed scenario emerge, with a wider support in the second case which reaches substantially more extreme boundary (log) values. This is shown in Figures 3.e and 3.f. In general, the higher the share of unionized firms in a given industry, the higher average real wage rate, as shown in Figure 3.g. It is important to notice, however, that this, as many other statistical results of properly-designed ABMs, are *emergent properties*, that is, results which are the aggregate outcomes of micro-level interactions and *not* assumed ex ante in the model design. Therefore, the property that deunionization induces (i) rising macro-level inequality, (ii) rising wage dispersion between firms, and (iii) polarization in wage growth dynamics, and represents an industry-specific emergent attribute.

The effects of deunionization are deep and reverberate into the structural core of the model, that is, into the dynamics of labour absorption, technological change,

and consumption patterns. Our model's industries display the typical S-shaped curve of diffusion (Franses, 1994), presenting the characteristic industrial lifecycle dynamics (Klepper, 1997). In the peak industry stage, the number of workers absorbed in a unionized setting is *higher* when compared to the case of coexisting non-union firms (about 17 vs. 14 thousand workers). This result holds across Monte Carlo average and median statistics. In turn, the different labour absorption levels are due to the pattern of consumption, as presented in Figure 3.h, where Engel's law is evaluated in each scenario. These curves show a direct interaction between the structure of income distribution and the consumption pattern over time. In a more egalitarian unionized set-up, the share of basic goods on the worker income decays over time at a pace significantly more tamed. Conversely, in the scenario populated also by non-union firms, the share of basic goods rapidly shrinks, leaving more space to luxury (durable) goods, accessible mostly to the richer workers. Therefore, as an endogenous property, the model is able to link inequality from two distinct perspectives, income and consumption. Inasmuch a more unequal society consumes and desires more luxury, durable goods, say, mansions, yachts, airplanes, more costly and less accessible those goods become to workers who are budget-constrained.

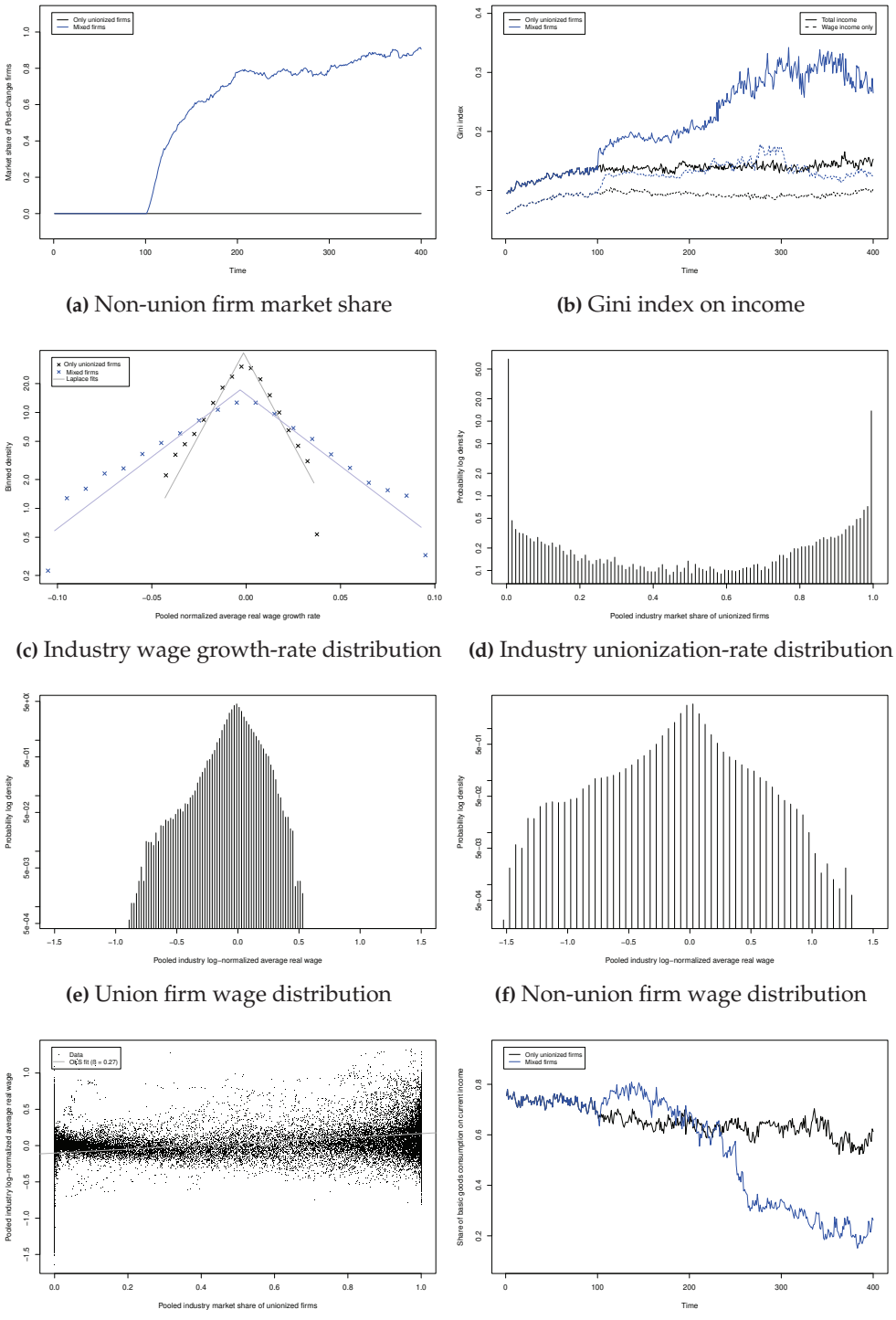
Figure 4 presents the macroeconomic feedback effects in terms of GDP growth (4.a) and unemployment rate (4.b). The presence of mixed firms affects the macroeconomic growth-rate distribution, shifting downward its support, that is, increasing the possibility of lower-growth episodes, and conversely, even if the medians are similar. The effects on employment are far more substantial, as the median unemployment is about 10 p.p. higher in the mixed-firms scenario, and around 15 p.p. over in the worst realizations. Unfortunately, these results seem in line with the historical trend.

4 Conclusions

There are four fundamental features of the K+S family of agent-based models. The first is the complementarity between a Schumpeterian engine of innovation and a Keynesian driver of demand generation. Second, the models entail the intrinsic

MICROECONOMIC STYLISED FACTS	MACROECONOMIC STYLISED FACTS
Skewed firm size distribution	Endogenous self-sustained growth with persistent fluctuations
Fat-tailed firm growth rates distribution	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 and net entry of firms in the market
Heterogeneous skills distribution	Persistent and counter-cyclical unemployment
Fat-tailed unemployment time distribution	Endogenous volatility of productivity,
Fat-tailed wage growth rates distribution	unemployment, vacancy, separation and
Cross-sectional Engel's law	hiring rates
Heterogeneous propensity to save and consume	Unemployment and inequality correlation
	Pro-cyclical workers skills accumulation
	Beveridge curve
	Okun curve
	Wage curve
	Matching function
	Engel's law
	Non-satiation in luxury goods
TECHNOLOGY-LEVEL STYLISED FACTS	SECTORAL-LEVEL STYLISED FACTS
Stepwise increase in technological frontier	**Product lifecycle**
Lower rate of radical versus incremental innovation	**Exponential age distribution**
Fast diffusion of dominant techniques	**Sectoral wage and productivity differentials**

Table 2: Stylized facts matched by the K+S model at different aggregation levels, newly added ones in bold.



(a) Non-union firm market share

(b) Gini index on income

(c) Industry wage growth-rate distribution

(d) Industry unionization-rate distribution

(e) Union firm wage distribution

(f) Non-union firm wage distribution

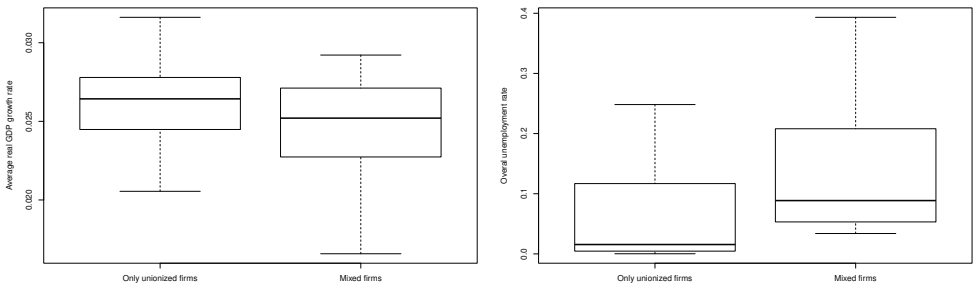
(g) Industry Unionization vs. wages

(h) Engel's law dynamics

Figure 3: Selected temporal and distributional model results presenting the declining unionization and the rising inequalities at the macro- and industry-level, and the change in consumption patterns. Series MC median computed for 100 runs in period $\hat{t} \in [1, 400]$. Distributions evaluated from 100 runs in $\hat{t} \in [301, 400]$.

MODEL PROPERTIES	EMPIRICAL EVIDENCE
Spurt dynamics in unionization/deunionization	Freeman (1998)
Positive correlation between unionization and inequality	Farber et al. (2021)
Deunionization as a result of within-industry dynamics and competition	Hirsch (2008)
Higher wage in union vs. non-union establishments	Lemieux (1998)
More homogeneous wages in union vs non-union establishments	Fortin et al. (2023)
Industry-level heterogeneous unionization rates	Fortin et al. (2023)
Positive correlation of unionization rate and wages at the industry level	Western and Rosenfeld (2011)

Table 3: Model emergent properties and supporting references on empirical literature.



(a) GDP growth-rate distribution **(b)** Unemployment rate distribution

Figure 4: Selected distributional model results presenting the macroeconomic second-order effects. Evaluated from 100 MC runs in period $\hat{t} \in [201, 400]$. Bar: median, boxes: 2nd and 3rd quartiles, whiskers: maximum and minimums.

duality of wages, which are an item of cost for individual firms but also an essential component of aggregate demand. Third, there is permanent dualism between the labour-shedding effects of technical change, via productivity improvements, and its employment-generation drive, by the introduction of new products. Finally, fourth, ubiquitous institutions shaping the behaviour of individual agents and their pattern of interaction.

In this chapter, we provide a new instantiation of the institutional embeddedness of the model architecture, focusing, as an illustrative example, on the coupling dynamics of competitive market forces and regulatory change in fostering deunionization. Our modelling exercise is quite in tune with the historical evidence. In fact, after 2010, five states in the Northwest US have introduced right-to-work (RTW) laws, an institutional change disfavouring unionization. Empirical evidence has shown that such laws weakened workers' unionization rights. These five states joined a bulk of states, mostly in the South and Midwest, historically adopting RTW laws since the introduction of the Taft-Hartley Act in 1947. The recent adoption of RTW laws has been accompanied by two macro long-run structural and institutional trends, namely, declining unionization and increasing inequality. How does one interpret such pattern? Can complexity economics provides a coherent representation about the effects of declining unionization? Can deunionization be a driver of increasing inequalities, both at the workplace and at the macroeconomic level? Which is the dynamics of labour absorption when non-union firms prevail? May wage inequality be also reflected in the consumption realm?

These are some of the questions that we try to answer using the multi-sector, labour-augmented K+S model. The proposed model is able to reproduce phase transitions with tipping points, such as the spurt dynamics in deunionization, but also to account for cumulative, long-lasting propagation mechanisms, at different aggregation levels and time scales. Such features are essential to properly model complex systems exhibiting self-organizing criticality, a concept described in chapter 9 of the present volume (Bouchaud, 2024). Deunionization does not simply affect the wages workers receive in the firm where they are employed. It also propa-

gates to the macro level, affecting the lifecycle pattern of industries, and the long-run dynamics of the consumption structure, via the Engel's law. In this respect, macro-evolutionary, agent-based models appear to be a formidable tool to assess the transformation mechanisms of the capitalist machine, a multi-level, multi-scale structure of production and exchange, whose feedbacks propagate with mixed speeds, and manifest in erratic ways.

Other applications of the current model include the analysis of the relationship between product market performance versus labour market concentration, consumption-pattern change and inflation dynamics, the hysteretic impact of firing and plant closures during crises, monopsony in the labour and product markets due to the rise of giant firms. Including, more generally, the effects of changes in union power and quit rates, or labour regulation reform, as the introduction/abolition of a minimum wage. New avenues of research certainly include embedding multidimensional forms of inequality, such as the ones linked to distinct group attributes, i.e., gender, race, exposure to diseases and pollution. Extensions of the model able to describe the changing role of social institutions, particularly the role of welfare state and the provision of public goods, are other complementary lines of research.

In general, the capitalist system rapidly changes, at an unpredictable pace, at least in its details and timing. This means that any interpretation of such dynamics in terms of equilibrium models will be unavoidably badly off the mark. Conversely, evolutionary ABMs seems to be promising candidates to face such a challenge.

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