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QUADERNI DEL DIPARTIMENTO
DI ECONOMIA POLITICA E STATISTICA

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The difficult task of changing while growing

n. 849 – Gennaio 2021

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January 2021

Abstract

This article develops a small-scale agent-based model to investigate the interplay between heterogeneous agents, institutions and technological change. By acknowledging the concept of behavioural dispositions, we differentiate between *changers*, *neutrals*, and *deniers.* Our research question is further motivated using data from the last two waves of the World Values Survey. The composition of the population is endogenously determined taking into account that reasoning is context-dependent. As we increase the degree of interaction between agents, a bi-modal distribution with two different basins of attraction emerges: one around an equilibrium with the majority of the population supporting innovative change, and another with most agents being suspicious of innovation. Neutral agents play an important role as an element of resilience. Conditional on their share in equilibrium, an increase in the response of the respective probability functions to growth results in a super-critical Hopf-bifurcation, followed by the emergence of persistent fluctuations. Numerical experiments on the basin of attraction also reveal the birth of a periodic hidden attractor. The long-run cycles we obtain indicate that economies are more likely to be path-dependent than what conventional approaches usually admit. As the productive structure evolves, the institutional framework is transformed and reinforces technological change in a cumulative way.

JEL: O11, O33, P11

*We are grateful to James Newell, Nita Handastya, Roberto Iacono, and Stefano Di Bucchianico for their careful reading and suggestions for improvement. A special thanks goes to Filippo Belloc for insightful discussions during the preparation of an earlier draft of the article. The usual caveats apply.

1 Introduction

Institutions are a key feature in the analysis of how agents deal with uncertainty. While it is widely accepted that innovative change demands a set of institutional adjustments, questions such as how, or even whether, badly performing economies may be able to design and implement "good" institutions remain open. This article is an attempt to provide some answers under the evolutionary premise that, even though they might appear as exogenous to the individual agent, institutions are essentially endogenous to the economic system (Aoki, 2007, 2011). By means of a small-scale agent-based model, we show that, as the productive structure evolves, the institutional framework is transformed reinforcing technological change in a cumulative way.

Human action and interaction need to be understood as resulting from shared habits of action and thought (Nelson, 2002). Agents construct mental models to interpret and produce expectations characterised by shared inter-subjectivity (Denzau and North, 1994; Knight and North, 1997). In other words, individual economic actors operate within cultural contexts that strongly influence their behaviour (Mazzoleni and Nelson, 2013). This structure of cognitive systems creates a baseline motivation to shape "reality" such that the human environment becomes a construct of rules and conventions that define the framework of social interchange (Boyer and Petersen, 2012, 2013).

Reason, deliberation and choice have evolved in humans into a bedrock of habits and instincts which in turn have a much longer evolutionary history (e.g. Hodgson, 2010). This means that deliberations are preceded by unconscious brain processes. Instincts or dispositions are not the antithesis of reason. On the contrary, modern psychology and recent findings in neuroscience seem to suggest that rationality and intelligence are rather their extensions (see Plotkin, 1994; Wegner, 2002; Libet, 2004). By acknowledging the concept of behavioural "dispositions" (Hayek, 1952), we differentiate between three types of agents: *changers*, *neutrals*, and *deniers*. The first group embraces innovative change, adopting a favourable attitude towards it. On the other hand, deniers are those who oppose innovation, basically defending the *status quo*, while neutral agents are either indifferent or disenfranchised. The capacity of adaptation of the economy is given by the institutional framework supported by the prevailing disposition of agents towards change.

When it comes to the production technology, we model it in a parsimonious way by distinguishing between the well-known "standing on shoulders" and "stepping on toes" effects (Jones, 1995). Changes in the former are supposed to depend on the correspondent set of adaptation capabilities. Moreover, one should notice that variations in the long-run rate of growth are likely to affect how individuals perceive the gains from advances in the technological frontier, thus, influencing the composition of the population in terms of their attitudes. Taking into account that reasoning is context-dependent, we tackle that issue making use of a mechanism that resembles a smooth approximation of the Best Reply dynamics, i.e. the Logit dynamics, parametrised by the intensity of choice as in Brock and Hommes (1997) (see also Hommes and Ochea, 2012).

Our resulting 3-dimensional nonlinear dynamic system is compatible with a weak representation of hysteresis. A dynamic system can be considered hysteretic when the trajectories of the endogenous variables exhibit some sort of path-dependency (Metcalfe, 2001; Dosi et al., 2018). As we increase the intensity of choice, which captures the degree of interaction between agents, a bi-modal distribution with two different basins of attraction emerges: one around an equilibrium with the majority of the population supporting innovative change, and another with most agents being suspicious of innovation. Neutral agents play an important role as an element of resilience. Conditional upon their share in equilibrium, an increase in the response of the respective probability functions to growth leads to a super-critical Hopf-bifurcation, resulting in persistent endogenous fluctuations. A numerical investigation of the basins of attraction reveals that the separatrix between the two solutions is a function of the sensitivity of agents to growth, and under certain conditions we might have the birth of a hidden periodic attractor.

Throughout history, the succession of episodes of economic prosperity and falling-behind, such as England during the industrial revolution or East-Asia in the 19th century, suggest that institutional and technological change are indissolubly fused. They cannot be satisfactorily explained by looking only at one dimension of the problem. In this respect, our model indicates that modern socialist-market China is managing a virtuous process of cumulative causation and only time will tell us how deep this process is going to be. Besides showing how the degree of interaction between heterogeneous agents might lead to the emergence of multiple equilibria, the cycles generated by the model indicate that economies are much more likely to be path-dependent than conventional approaches usually admit.

The economic interpretation of both hidden and standard persistent fluctuations is similar. They consist in a dynamic representation of long-run processes of cumulative causation. Nonetheless, we would like to highlight there is an extra flavour in our story. A hidden cycle of structural and institutional change may coexist with locally stable fixed points. In recent decades, historians have provided important insights into this phenomenon. To the best of our knowledge, we are the first to develop a formal representation of it. The empirical literature on institutional economics is heavily grounded on the idea that different attractors might even coexist but should be locally stable. By demonstrating the presence of a hidden orbit, our model suggests that we should be careful in the interpretation of standard econometric techniques.

The remainder of the paper is organised as follows. In the next Section, using data from the World Values Survey, we revisit some stylised facts showing that long-run growth seems to be positively related to favourable attitudes towards change. Section 3 develops our small-scale agent-based model and provides the formal proofs of the existence and stability of equilibria. In Section 4, by means of numerical simulations, we confirm that the Hopf-bifurcation is super-critical, bringing further insights into the nature of technological and institutional change. Some final considerations follow.

2 Some stylised facts

Frequently referred to as the "rules of the game", institutions can be understood as a combination of written laws, formal rules, informal behaviour norms, and shared beliefs about the world. Alternative definitions include the concept of systems of established and embedded social rules that structure social interactions (e.g. Hodgson, 2006) or, using game-theory language, the differentiation between the game-form and the endogenous equilibrium outcome of a game (Aoki, 2007). A review of this vast literature goes beyond the scope of this paper. Still, we would like to highlight the apparent convergence across strands of research on the contrast between societies whose past experiences condition them to regard innovative change with antipathy and those with favourable attitudes towards it.

Such a differentiation can be seen in the tension between inertia and innovation (Veblen, 1919), in the preference for the creation of "open access orders" rather than "natural states" (e.g. North et al., 2009), in the defence of "inclusive" rather than "extractive" economic and political arrangements (Acemoglu and Robinson, 2012), in the recognition of the role of a friendly environment for entrepreneurs and inventors (Mokyr, 2010), in the contraposition between risk-sharing and risk-taking cultures (Greif et al., 2012) among others (for a recent review, see Kingston and Caballero, 2009; Lloyd and Lee, 2018). Following a long tradition in evolutionary economics, we understand that institutions should be studied against the background of a set of human psychological dispositions that influence the effort needed to adopt and accept certain social arrangements (Boyer and Petersen, 2012).

Hence, we rely on data from the World Values Survey (WVS) to bring stylised insights into the correspondence between some of these behavioural "dispositions" and long-run growth. The WVS consists of nationally representative surveys conducted in almost 100 countries containing close to 90 percent of the world's population, using a common questionnaire. It seeks to help social scientists and policy makers to understand changes in the beliefs, values and motivations of people throughout the world. Data includes topics such as economic development, democracy, religion, gender equality, social capital, and subjective well-being. We make use of the three questions of this survey that are related to how people approach innovative change as well as the possible answers:

1. Future changes: More emphasis on technology.
    - Good thing, bad thing, don't mind.
2. Because of science and technology, there will be more opportunities for the next generation.
    - Scale from 1 to 10 where 1 means "complete disagreement" and a 10 means "complete agreement" with the statement.
3. The world is better off, or worse off, because of science and technology.
    - Scale from 1 to 10 where 1 means that "the world is a lot worse off" and 10 means that "the world is a lot better off".

Of course, going back at least to Acemoglu et al. (2002), the empirical literature on institutional economics has documented a positive relationship between certain institutional variables and growth. Still, to the extent that institutional design is deeply context-dependent, we must accept Chang's (2011) critique that statements and measures of "superior" institutions are flawed. For instance, a specific institution that matters for economic growth often does not operate similarly across societies (Ogilvie and Carus, 2014). Given the high degree of complementarity between pieces in the puzzle, attempts at changing historically established institutional structures have resulted in catastrophic aftermaths, as the Post-Soviet experience demonstrated (see Kirdina, 2014). The recent rise of China as a major player in the international arena provides further evidence of the arbitrariness of such measures.

It is not our purpose to follow a similar route here. However, we do believe that societies that are more open to change are likely to find better ways to adapt to change. The crucial element is not a specific instrument or optimal path, but how society approaches the challenges imposed by innovation. Thus, we shall not engage in a quest for the ultimate determinants of economic prosperity. Rather, we aim to explore the mechanisms that make both institutions and technological change endogenous to each other, highlighting the role of behavioural dispositions. As pointed out in the Introduction, modern psychology and recent findings in neuroscience seem to suggest that instincts or dispositions are at the basis of reason.

Starting with the first question presented above, Fig. 1 shows the correlation between the average rate of growth and the share of those who see future technology as good, panels (a)-(b), or bad, panels (c)-(d). The slope does not change if we use a time-span of ten ($g10$) or twenty years ($g20$). A detailed description of the countries included in the analysis is reported in the Empirical Appendix. There is a positive correspondence between a favourable attitude towards change and long-run growth in both waves 6 and 7 of the WVS. On the other hand, we can observe a negative relationship between growth and unfavourable dispositions to innovation. Countries such as China exhibit high growth and very positive attitudes. This contrasts, for example, with Argentina that has been falling-behind in terms of relative per capita income, and also presents a greater share of agents with a suspicious attitude towards innovative change.

Fig. 2 reports similar correlations when applying a scale from 1 to 10 for how people see the impact of new technologies to present and future generations, as in questions 2 and 3. The higher the score, the higher is the associated long-run rate of growth. Overall, these findings seem to be in line with our previous discussion of the tension between innovation and inertia. In what follows, it is our purpose to provide a formal assessment of this stylised fact in terms of a small-scale agent-based model that considers the interplay between heterogeneous agents, technological and institutional change.

As pointed out by Frey (2019), the nature of technological change has varied significantly over time. This has influenced how societies face change. Comparisons between the traditional movement from agriculture to industry and the ongoing process of task-based mechanisation are nor straightforward. Moreover, causality is very much likely to go in both directions. If technological change is perceived to improve the quality of life in a given society, one should expect attitudes to become more favourable to innovation, thus leading to a gradual adoption of "open access orders" (as in North et al., 2009). In a cumulative fashion, this would give a further impulse to advances in the technological frontier. On the contrary, when innovation is persistently seen to damage well-being, agents are likely to become more sceptical towards change.

3 The model

Technical change is a slow-motion, long-run, process that involves costly replacements of interlocking elements. As the productive structure reshapes, institutions are transformed and reinforce each other in a cumulative way. We divide our narrative into two main blocks of equations: (i) mental models, and (ii) the production technology. The first block formalises the role of three different attitudes towards innovation and change. The second is related to production conditions and to how the structure of the economy adapts to the challenges imposed by the unknown.

3.1 Changers, deniers and neutrals

Reasoning and deliberation have evolved in humans into a bedrock of instincts and habits with a long evolutionary history (e.g. Hodgson, 2010). One of the most primitive dispositions documented by evolutionary psychology is the "fight-or-flight" response. Such term represents the choices our ancient ancestors faced when confronted with danger. Physiological

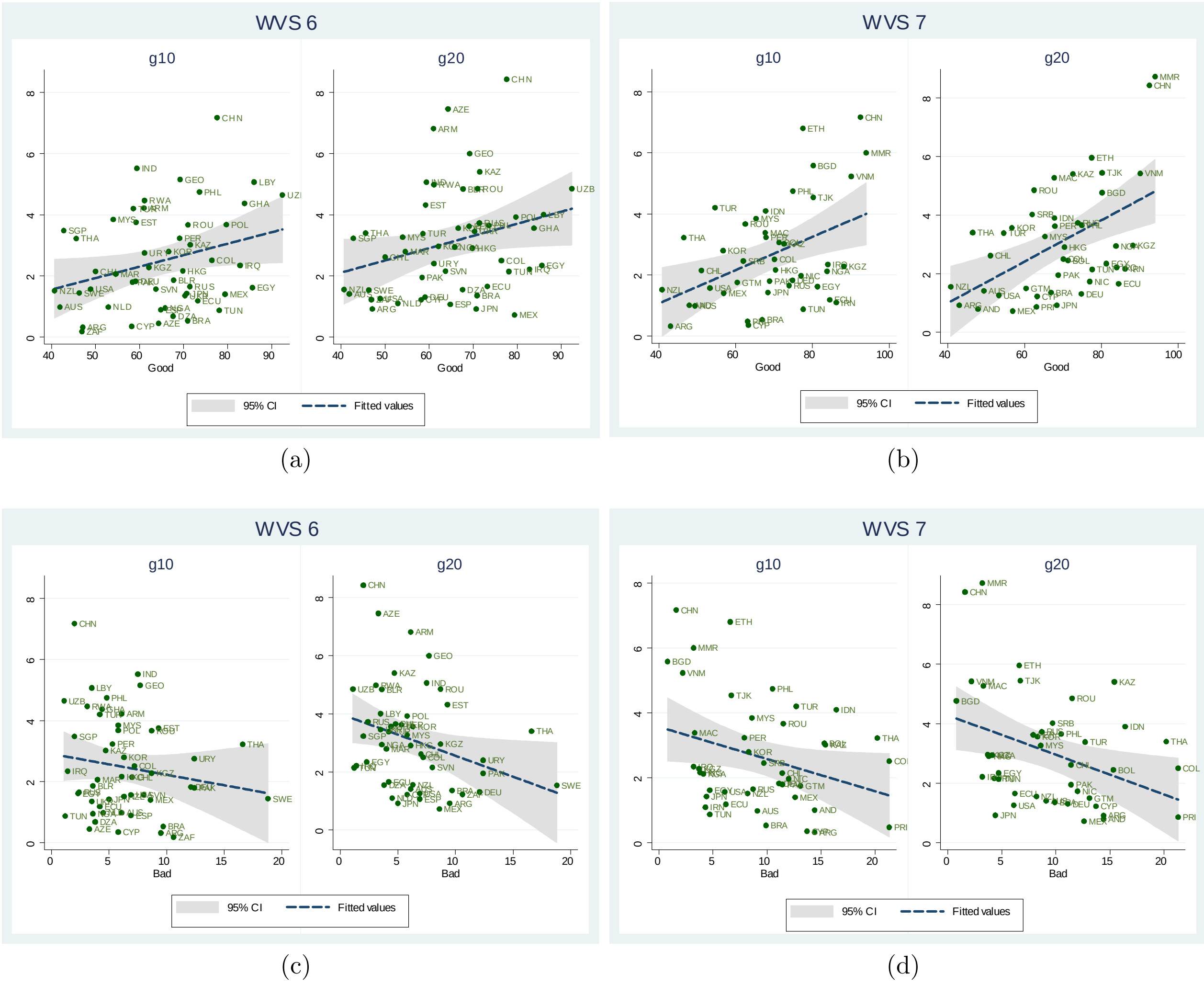
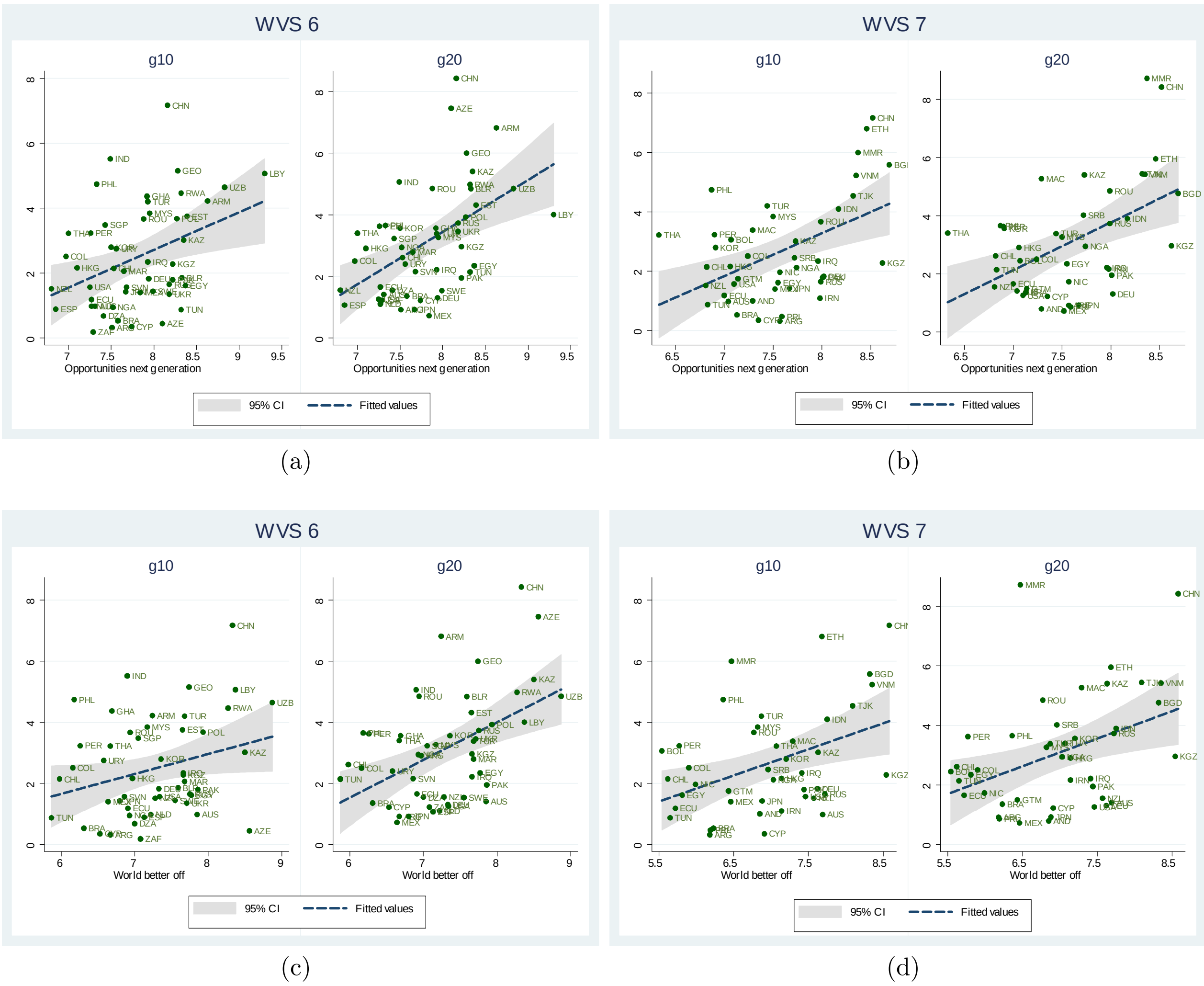


Figure 1: Correlations between long-run growth and the share of those who see future technology as good or bad.



(a) (b)

(c) (d)

Figure 2: Further insights on attitudes towards change and long-run growth.

and psychological responses prepared the body either to fight or escape. Under the premise that instincts are not the antithesis of reason, but on the contrary, the latter is rather an extension of them (see Plotkin, 1994; Wegner, 2002; Libet, 2004), we argue that a similar dispositional mechanism underlies how agents face innovative change.

When confronted with a new technology agents might "fight", which in our case implies adopting a positive attitude towards the conditions imposed by change. Alternatively, they might engage in "flight", opposing innovation and, consequently, defending the *status quo*. Or instead, they may be indifferent. We refer to each group as *changers* (L^C), *deniers* (L^D), and *neutrals* (L^N), respectively:

$$\bar{L} = L^C + L^D + L^N \tag{1}$$

where for simplicity, total population ($\bar{L}$) is assumed to be constant.[1]

Over the past three decades, different contributions have formalised switches between two heuristics in agent-based models (for a review, see Franke and Westerhoff, 2017). A transition between three states can be found in Foster and Flieth (2002), while considerations on five states appear in Gomes and Sprott (2017). The present paper follows Franke and Westerhoff (2019) in distinguishing between three types of agents and assuming that an individual cannot change her/his mind from one extreme to the other. Such a process is intermediated by a state in which the agent evaluates her/his belief and might move to the opposite group or return to the previous position:

$$L^C \Leftrightarrow L^N \Leftrightarrow L^D$$

Society either tries to adapt to the new scenarios created by change or reinforces institutions that maintain the *status quo*. In both cases, action results from the confrontation between L^C and L^D. Indifferent or neutral individuals do not take active part in the public debate and, therefore, cannot directly influence the intensity of movements at the collective level (m), defined as

$$m = \frac{L^C - L^D}{\bar{L}} \tag{2}$$

such that $m \in (-1, 1)$. When all the population is formed by "changers", $m = 1$. On the other hand, when everybody rejects innovation and supports the *status quo*, we have $m = -1$. Notice, however, that the existence of a group that does not have a strong position regarding the direction society should take – the so-called neutrals – implies that m lies in between this range. Hence, its maximum and minimum are given by the share of L^C and L^D over $\bar{L}$, respectively. Differentiating Eq. (2) with respect to time, we have:

$$\dot{m} = \frac{\dot{L}^C - \dot{L}^D}{\bar{L}} \tag{3}$$

Neutral agents might not play a strong and visible role, but they do occupy a resilience position (n) captured by their proportion in the population:

$$n = \frac{L^N}{\bar{L}} \tag{4}$$

[1] One could also argue that L^N comprises changers and deniers who are disenfranchised. In that case, even if these individuals have a certain disposition for action, a combination of reasons that go from physical limitations to currently valid social rules make them unable to signal it. As a result, their behaviour is *as if* they were neutrals.

Intuitively, a society formed only by changers and deniers may be prone to conflict. The attitude of the two groups regarding innovation is completely different from a conceptual point of view. For example, in the extreme case in which $n = 0$, an equal distribution between L^C and L^D, such that $m = 0$, stands as a state of complete polarisation. Alternatively, scenarios with $L^C \gtrless L^D$ still underlie strong opposition in decision making. Indifferent dispositions bring malleability to the social tissue, allowing for smoother adaptation. We shall come back to this issue in detail when demonstrating the existence of one or more equilibrium points and their local stability properties. Taking time derivatives of both sides of Eq. (4), we obtain:

$$\dot{n} = \frac{\dot{L}^N}{\bar{L}} \tag{5}$$

Dispositions are not just "manna from heaven". We assume each individual agent is a changer, denier or neutral with probability p^C, p^D, and p^N, respectively, such that $\sum_{j=C,D,N} p^j = 1$. Thus, given that it is not possible to jump from being a changer to a denier and *vice-versa*, it follows that:

$$\begin{aligned} \dot{L}^C &= L^N p^C - L^C p^N \\ \dot{L}^D &= L^N p^D - L^D p^N \\ \dot{L}^N &= \left(L^C + L^D\right) p^N - L^N \left(p^C + p^D\right) \end{aligned} \tag{6}$$

Substituting Eq. (6) into (3) and (5), while taking advantage of the definitions of m and n, we obtain:

$$\begin{aligned} \dot{m} &= n\left(p^C - p^D\right) - m p^N \\ \dot{n} &= p^N - n \end{aligned} \tag{7}$$

such that adjustments in the intensity of the public debate as well as in the degree of social inertia respond to the probability functions.

It is possible, for pedagogical purposes, roughly to separate the set of evolutionary dynamics into two classes. The first corresponds to Darwinian imitation represented by the well-known Replicator equation.[2] The second class corresponds to pairwise comparison or belief-based. Our narrative is closer to this last approach, in particular to a smooth approximation of the Best-Reply dynamics, i.e. the Logit dynamics, parametrised by the intensity of choice (β), as in Brock and Hommes (1997). Hence, define:

$$\begin{aligned} p^C &= \frac{\delta \exp(\beta s)}{\exp(\beta s) + \exp(-\beta s)} \\ p^D &= \frac{\delta \exp(-\beta s)}{\exp(\beta s) + \exp(-\beta s)} \\ p^N &= 1 - \delta \end{aligned} \tag{8}$$

where s is an index which includes a broad set of variables that are likely to influence the probability of exhibiting a certain attitude, and δ stands as a discount factor of the degree

[2] Applications to the theory of institutions include Hodgson and Knudsen (2006, 2010), among others. The former is a particularly interesting reference because it develops a model based on NK-fitness landscapes that highlights the tension between inertia or conservatism and innovation in individual and organisational behaviour.

of polarisation over the probability functions. While from a technical point of view this last variable guarantees that $\sum_{j=C,D,N} p^j = 1$, it also has an important economic content, as we will show when presenting the "interaction bridges" between the two blocks of equations of the model. The intensity of choice goes from zero – when the switching rate is almost independent of the actual performance of the alternative strategies – to infinity – when the probability of switching is equal to one.[3]

Substituting Eq. (8) into (7), we obtain the dynamics of collective action and resilience as a function of s and δ:

$$\begin{aligned} \dot{m} &= n\delta \tanh(\beta s) - m(1-\delta) \\ \dot{n} &= 1 - \delta - n \end{aligned} \tag{9}$$

postponing to the next pages how this structure depends on the technological conditions of the economy. Still, it is worth noticing that, for the moment, $\partial\dot{m}/m < 0$ and $\partial\dot{n}/n < 0$ stand as automatic stabilisers of the system. This comes from the fact that the probability of becoming neutral spontaneously responds to the size of non-neutral groups in the population. For a given set of probabilities, an increase in n implies a greater number of individuals turning to a non-indifferent disposition. On the other hand, a higher or lower m is associated with a greater share of changers or deniers, respectively, increasing the pool of those who might turn to neutrality.

3.2 Production technology

Suppose a generic production function:

$$Y = f(A, K),\ f_A > 0,\ f_K > 0,\ f(0,0) = 0 \tag{10}$$

where Y is output, A corresponds to productivity or knowledge, and K stands for the capital stock. To keep the algebraic steps as simple as possible, the population is supposed to match the labour force, being constant and fully employed.[4]

Log-differentiating the expression above, we obtain:

$$\frac{\dot{Y}}{Y} = \left[\frac{\partial f}{\partial A}\frac{A}{f(\cdot)}\right]\frac{\dot{A}}{A} + \left[\frac{\partial f}{\partial K}\frac{K}{f(\cdot)}\right]\frac{\dot{K}}{K} \tag{11}$$

For a constant output-capital ratio, we have:

$$\frac{\dot{Y}}{Y} = \frac{\dot{K}}{K} = g \tag{12}$$

[3] Evolutionary dynamics in an n-strategic game define a proper $n-1$ dynamic system. Hommes and Ochea (2012) recall that there are no-generic Hopf-bifurcations under Replicator dynamics on the 2-simplex. Furthermore, they show the existence of stable orbits and multiple interior steady-states under Logit dynamics. In what follows, we shall show that this is also the case here, and provide an economic interpretation of the resulting long-run cycles. For a deep game theory assessment of cultural evolution, see Bowles and Gintis (2013).

[4] Such an assumption is in line with more *mainstream* as well as some evolutionary growth models. Alternative theories of growth and distribution, on the other hand, have highlighted that aggregate demand matters also in the long-run (e.g. Dosi et al., 2010; Franke, 2018). Introducing employment or income distribution considerations would increase the dimension of the dynamic system without adding much to our story. If we manage to convince the reader of the usefulness of our approach, future research should increase the realism of the model.

To simplify notation, redefine $\dot{A}/A = g_A$. Substituting Eq. (12) into Eq. (11), the rate of growth of output is given by:

$$g = \varepsilon g_A \tag{13}$$

where $\varepsilon = \frac{\partial f}{\partial A}\frac{A}{f(\cdot)} / \left[1 - \frac{\partial f}{\partial K}\frac{K}{f(\cdot)}\right] > 0$ establishes a link between the elasticities of output with respect to knowledge and capital. Differentiating Eq. (13) with respect to time, we obtain:

$$\dot{g} = \varepsilon \dot{g}_A \tag{14}$$

Economic growth is caused by changes in the distribution of operative routines at the firm level (see Nelson and Winter, 1982). A routine involves a collection of procedures which, taken together, result in predictable and specific outcomes (e.g. Nelson, 2002). Growth is associated with the creation of superior new routines and the widespread use of superior against inferior ones. This can happen either through the relative expansion of organizations that perform well or by the adoption of better production technologies.

The production of new ideas comprises two opposing forces, namely, "standing-on-shoulders" and "stepping-on-toes" (Jones, 1995). They are both cumulative effects to the extent that (i) new technologies depend directly or indirectly on the sum of past innovation breakthroughs, while (ii) as production increases and the productivity frontier expands, the current techno-economic paradigm reaches maturity and, therefore, it becomes more difficult to be innovative (Perez, 2010). One could argue that the development of an international patent system influences the two dimensions. On the one hand, it secures intellectual property rights. On the other hand, it becomes costly to move forward as there is an increasing fee for the introduction of new goods, services or practices into the system (Pagano, 2014).

For instance, the capital stock in a certain country consists of a complex web of interlocking parts. It is difficult to make replacements without the costly rebuilding of other elements because they were initially built to fit together. As the scale of production increases and the technologies that enable such changes are developed, significant problems arise in terms of the organization of corporations, going from management of tangible and intangible assets to labour and legal issues (Andreoni and Chang, 2019). In mathematical terms:

$$g_A = S - T \tag{15}$$

where S and T capture the first and the second effect, respectively.

To keep our narrative as simple as possible, suppose variations in S are determined by the pace at which past innovation drives the development of new technologies (α) while T directly mirrors the rate of capital accumulation:

$$\begin{aligned} \dot{S} &= \alpha \\ \dot{T} &= g \end{aligned} \tag{16}$$

where α can also be seen as a *proxy* for the capacity of adaptation of the economy as it reflects the dynamics of the "standing-on-shoulders" effect. High values of this variable are related to the effective operation and advancement of physical and social technologies (Nelson, 2008). Recent evidence at firm level indicates that the experience of rapid catching-up by China is deeply rooted in a process of learning and "creative restructuring" of domestic enterprises (see Yu et al., 2015). Sustaining growth over the long-run requires that the economy adapts fast enough to introduce new techniques as well as goods and services in a continuous way (e.g. Dosi et al., 2020).

Differentiating both sides of Eq. (15) with respect to time and substituting Eq. (16) into the resulting expression, it follows that changes in the rate of growth of productivity or knowledge depend on the difference between these two forces:

$$\dot{g}_A = \alpha - g \tag{17}$$

Substituting Eq. (17) into Eq. (14), the rate of growth of output will follow a similar adjustment, intermediated by the shape of the production function:

$$\dot{g} = \varepsilon \left(\alpha - g\right) \tag{18}$$

such that growth will accelerate or decelerate depending on $\alpha \gtrless g$. When $\alpha > g$, the capacity of adaptation of the economy is greater than the "stepping on toes" effect. Past technologies create new production opportunities at a greater speed than the costs of adapting to change. As a result, one should expect an increase in g. On the contrary, when $\alpha < g$, a saturation of the techno-economic paradigm is associated with a reduction in long-run growth.

3.3 The Interaction bridges

So far, we have presented the main blocks of equations of the model without allowing for interactions between them. This is going to happen through two main channels. First, in line with the stylised facts revisited in Section 2, we assume that the capacity of adaptation of the economy is a positive function of the difference between the strength of those who support change and those who stand for the *status quo*:

$$\alpha = \alpha\left(m\right), \ \alpha'\left(\cdot\right) > 0, \ \alpha\left(-1\right) > 0 \tag{19}$$

that is, for a given n, societies that are more open to change will find better ways to adapt to change.

Eq. (19) is not and should not be understood as a defence of the belief that free-markets and strong protection of private property rights are somehow "superior" institutions. In this, we very much agree with Chang's (2011) critique of more conventional approaches. We believe that the recent rise of China as a major international player and the catastrophic aftermaths in several countries of the former Soviet Union stand as examples that institutional design is context-dependent. Acknowledging the role of behavioural dispositions in social reasoning, our claim only makes reference to the collective attitude towards change. As we will show in what follows, the latter is conditional on how agents perceive the benefits of technological change.

To process and make sense of new information, agents require a paradigm framework. This means that our understanding of the world is necessarily acquired through social interactions. Obtaining such a cognitive apparatus involves extensive processes of interaction, socialisation, and education. Thus, cognition is a social as well as an individual process (Hodgson, 2006). Old-institutionalists identified two main determinants of human behaviour: instinctive factors and habits (Veblen, 1898; Clark, 1918). Both of them are deeply related to the well-documented phenomena of reasoning under *conformity bias*. It consists in identifying well-adapted kinds of behaviour by drawing on their frequency in a given cultural context (e.g. Kameda and Diasuke, 2002; Cialdini and Goldstein, 2004). Individuals are more likely to pick the behavioural variant which is aligned with the majority of the group members (see Cordes, et al. 2010; Cordes, 2019).

Moreover, as argued throughout this paper, if change is perceived to improve the quality of life, one should expect that dispositions are to become more favourable to innovation. On the other hand, when the new conditions imposed by change are not perceived as beneficial, agents are likely to adopt a more sceptical view of new technologies. Using the first example provided by Frey (2019), the discovery of the light bulb improved collective well-being, despite the costs for lamplighters who opposed this technology for obvious reasons. One could argue that even they probably found less hazardous and better-paying jobs afterwards.

We thus assume that s is given by:

$$s = m + \mu \dot{g} \tag{20}$$

where $\mu > 0$ stands for the response of the index to variations in g. In this way, we formally consider both the influence of social context on agents' perceptions of the world as well as the impact of the fruits of innovation on well-being. A higher m and accelerating growth are associated with a higher probability of being L^C, as in (8). On the contrary, a falling m together with a declining $\dot{g}$ increase the probability of being L^D.[5]

To close the model, we allow the discount factor in the probability functions to respond to changes in economic performance:

$$\delta = \delta\left(\dot{g}\right), \ \ \delta'\left(\cdot\right) \begin{cases} > 0 \text{ if } \dot{g} > 0 \\ = 0 \text{ if } \dot{g} = 0 \\ < 0 \text{ if } \dot{g} < 0 \end{cases}, \ 0 < \delta\left(0\right) < 1 \tag{21}$$

that is, when the long-run rate of growth is either increasing or decreasing, there is a strong social consensus that reduces the likelihood of having a neutral attitude. This is due to the fact that it is easier to see that things are getting better or worse when $|\dot{g}|$ is far from zero. On the contrary, the closer $|\dot{g}|$ is to zero, the higher the degree of neutrality or indifference, as the outcome of current institutional arrangements is unclear. Under such circumstances, people are prone to have second thoughts and become less confident over which part to side with. As a consequence, there is an increase in the probability of being L^N.

3.4 Dynamic system

Substituting Eq. (19) into Eq. (18) gives us the behaviour of the long-run rate of growth as a function of attitudes towards change in the population. Then, inserting Eqs. (21) and (20) into Eq. (9), we obtain the dynamics of m and n. In this way, we arrive to a 3-dimensional dynamic system:

$$\begin{aligned} \dot{g} &= \varepsilon\left[\alpha\left(m\right) - g\right] = h_1\left(g, m, n\right) \\ \dot{m} &= n\delta\left(\dot{g}\right)\tanh\left(\beta\left(m + \mu\dot{g}\right)\right) - m\left[1 - \delta\left(\dot{g}\right)\right] = h_2\left(g, m, n\right) \\ \dot{n} &= 1 - \delta\left(\dot{g}\right) - n = h_3\left(g, m, n\right) \end{aligned} \tag{22}$$

[5]Implicitly, we are assuming that an acceleration of growth is related to an improvement of life conditions. This is not always the case given that we are overlooking the inequality dimension and do not differentiate between types of innovation. Still, we must carefully prioritise what to discuss. Considerations on power and income distribution in an open-economy model that only distinguishes between two behavioural dispositions can be found in Dávila-Fernández and Sordi (2020).

In steady-state, we have $\dot{g} = \dot{m} = \dot{n} = 0$, so that the equilibrium conditions are given by:

$$\begin{aligned} \bar{g} &= \alpha(\bar{m}) \\ \bar{n}\delta(0)\tanh(\beta\bar{m}) &= \bar{m}[1-\delta(0)] \\ 1-\delta(0) &= \bar{n} \end{aligned} \tag{23}$$

From the first expression, it follows that the long-run rate of growth is equal to the pace at which past innovation drives the development of new technologies, i.e. the capacity of adaptation of the economy, which in turn depends on the prevailing behavioural dispositions. It follows from the second expression that, in equilibrium, the probability of having an active or a passive role in society is the same. Finally, the share of neutral agents is negatively related to the discount factor in the probability functions.

Given conditions (23), we can state and prove the following Proposition regarding the existence of a unique or multiple equilibrium solutions.

Proposition 1 *When the "intensity of choice" is weak enough i.e. $\beta \leq 1/\delta(0)$, the dynamic system admits a unique equilibrium solution:*

$$P_1 = (\bar{g}_1, \bar{m}_1, \bar{n}_1) = (\alpha(0), 0, 1-\delta(0))$$

On the other hand, when the "intensity of choice" is sufficiently strong, i.e. $\beta > 1/\delta(0)$, the following two additional equilibria emerge:

$$\begin{aligned} P_2 &= (\bar{g}_2, \bar{m}_2, \bar{n}_2) = (\alpha(\bar{m}_2), \bar{m}_2, 1-\delta(0)) \\ P_3 &= (\bar{g}_3, \bar{m}_3, \bar{n}_3) = (\alpha(\bar{m}_3), \bar{m}_3, 1-\delta(0)) \end{aligned}$$

where

$$\bar{m}_2 < 0 \text{ and } \bar{m}_3 > 0$$

such that

$$\tanh(\beta\bar{m}) = \frac{\bar{m}}{\delta(0)}$$

Proof. See Appendix B.1 ■

The correspondence between β and $\delta(0)$ determines a threshold after which a Pitchfork bifurcation occurs and the system admits three equilibrium points instead of only one. Recall that β stands for the intensity of choice and goes from zero to infinity. Moreover, given Eqs. (8) and (20), it also captures the degree of interaction among agents. A low interplay between them, $\beta \leq 1/\delta(0)$, is associated with a unique equilibrium solution such that $L^C = L^D$. As interaction increases, $\beta > 1/\delta(0)$, we end up with two additional solutions: one with lower growth and the prevalence of negative attitudes, $L^D > L^C$, and another with higher growth and the majority of non-neutral agents being open to change, $L^D < L^C$. A higher share of L^N in the population is associated with a lower $\delta(0)$ and, thus, the less likely it is that the system has a Pareto superior equilibrium and a Pareto inferior one.

Regarding the local stability properties of P_1, P_2, and P_3, we can state and prove the following Propositions.

Proposition 2 *In the case $\beta \leq 1/\delta(0)$, a sufficient condition for the local stability of the unique equilibrium P_1 requires*

$$\mu \leqslant \frac{1-\delta(0)\beta}{\delta(0)\beta\varepsilon\alpha'(0)} \tag{24}$$

i.e., that attitudes are only weakly responsive to changes in the long-run rate of growth.

Furthermore, when μ is in the neighbourhood of the critical value

$$\mu_{HB} = \frac{\varepsilon + \bar{n}_1 \left[1 - \delta(0)\beta\right]}{\bar{n}_1 \delta(0) \beta \varepsilon \alpha'(0)}$$

the dynamic system admits a family of periodic solutions.

Proof. See Appendix B.2. ■

Proposition 3 *In the case $\beta > 1/\delta(0)$, the equilibrium solution P_1 is a saddle point. A sufficient condition for the local stability of the other two equilibria P_2 and P_3 requires that attitudes' responses to changes in the long-run rate of growth are weak enough, such that:*

$$\mu \leqslant \frac{1 - \delta(0)\beta F_i}{\delta(0)\beta\varepsilon\alpha'(\bar{m}_i) F_i}, \ i = 2, 3 \tag{25}$$

where

$$F_i = \left[1 - \tanh^2(\beta \bar{m}_i)\right]$$

On the other hand, when μ is in the neighbourhood of the critical value

$$\mu_{HB} = \frac{\varepsilon + \bar{n}_i \left[1 - \delta(0)\beta F_i\right]}{\bar{n}_i \delta(0) \beta \varepsilon \alpha'(\bar{m}_i) F_i}$$

the dynamic system admits a family of periodic solutions.

Proof. See Appendix B.3. ■

When there is little interaction among agents, the unique equilibrium point is locally stable provided that the sensitivity of the probability functions to growth is sufficiently low. As we increase the parameter capturing the intensity of choice, P_1 loses stability and becomes a saddle point. On the other hand, the emerging solutions, P_2 and P_3, are locally stable as long as μ is sufficiently small. This characterises the bi-modal distribution of countries that we referred to in the Introduction. It may happen, however, that $\mu > \mu_{HB}$, in which case a Hopf-bifurcation occurs. For $\beta \leq 1/\delta(0)$, the dynamic system admits a family of periodic solutions around the unique equilibrium, while for $\beta > 1/\delta(0)$, a closed orbit emerges around P_2 and P_3. Depending on initial conditions, economies with very similar characteristics might end up in different basins of attraction, including the possibility of long-wave cycles of institutional and technological change.[6]

It is interesting to notice that:

$$\begin{aligned} \lim_{\delta(0)\to 0} \mu_{HB} &= +\infty \\ \lim_{\delta(0)\to 1} \mu_{HB} &= +\infty \end{aligned}$$

[6] The existence part of the Hopf-bifurcation theorem leaves us in the dark regarding the nature of the bifurcation. It could be supercritical, when the Maximum Lyapunov Exponent (*MLE*) is negative and, thus, orbits are stable. On the other hand, when *MLE*> 0, an unstable cycle exists and we say the bifurcation is subcritical. A degenerate case occurs when *MLE*$= 0$. However, given that it is not a simple task to provide an economic interpretation of the (long) required conditions to obtain the *MLE*, we preferred to rely directly on numerical simulations. A rigorous reference to the topic can be found in Kuznetsov (2004, pp. 157–187).

meaning that the system is more likely to be stable when the equilibrium share of neutral agents in the population is either very high or very low, given that $n = 1 - \delta(0)$. This tells us something about the role of L^N in institutional change. For a given intensity of choice, when the proportion of indifferent behavioural dispositions is close to one, such that $\delta(0) \approx 0$, the economy would be somehow stagnant but very stable. On the other hand, while a reduction in $\bar{n}$ is associated with the emergence of additional high and low growth equilibria, the disappearance of neutrals makes P_2 and P_3 very stable. Thus, for intermediate values of L^N, in the neighbourhood of $\partial\mu_{HB}/\partial\delta(0) = 0$, the system is more likely to admit periodic solutions.

Focusing on the case in which there is sufficient interaction between agents, i.e. $\beta > 1/\delta(0)$, the discussion above illustrates the instrumental malleability that indifferent attitudes bring to the social tissue. An economy initially trapped in the "bad" equilibrium is unlikely to move towards the basin of attraction of the "good" one without those who apparently do not take an active part in the public debate. This results from the fact that negative attitudes prevail over the other two groups, leading to the consolidation of an institutional framework associated with a small capacity of adaptation. Small variations in the long-run rate of growth do little but to reinforce dominant dispositions. It is the enlargement of the neutral group that allows changes in g slowly to modify attitudes. To provide a more concrete view of the dynamic properties of the model and the economic intuition of our narrative, we now proceed by presenting some numerical simulations.

4 Numerical simulations

We must first of all choose functional forms for the two behavioural expressions of the model, $\alpha(\cdot)$ and $\delta(\cdot)$. We specified them as follows:

$$\begin{aligned} \alpha(m) &= \alpha_0 + \alpha_1 m \\ \delta(\dot{g}) &= \delta_0 + \dot{g}^2 \end{aligned} \tag{26}$$

such that the properties of Eqs. (19) and (21) are satisfied. Parameters α_0 and δ_0 are supposed to capture all variables that influence the capacity of adaptation and the discount factor over the probability functions, respectively, not determined inside the system. On the other hand, α_1 stands for the structural reaction to the intensity of movements at the collective level. A high α_1 is associated with more efficient responses to change for a given m.

In order to choose plausible parameter values, we have considered the evidence provided in this paper as well as magnitudes frequently used in the agent-based literature of switches between heuristic (e.g. Hommes and Ochea, 2012; Franke and Westerhoff, 2017). Although this selection has an illustrative purpose only, similar qualitative results are observed for wider ranges. Our reference values are:

$$\alpha_0 = 0.02, \ \alpha_1 = 0.01, \ \delta_0 = 0.5$$

such that for

$$\beta = 2$$

a Pitchfork bifurcation occurs while μ remains as our Hopf-bifurcation parameter.

Fig. 3 displays the emergence of the limit cycle in the case in which there is little interaction among agents. Panel (a) corresponds to the case in which the sufficient stability condition in Proposition 2 is satisfied. It guarantees monotonic convergence to the unique equilibrium point. A violation of that condition is associated with fluctuations of decreasing amplitude, as depicted in panel (b). Nonetheless, the solution P_1 is still locally stable. As we further increase the response of s to variations in the rate of growth, a super-critical Hopf-bifurcation occurs, giving rise to persistent endogenous fluctuations. When $\beta = 2$, we have that $\mu_{HB} = 200$. Panels (c) and (d) show that the periodic orbits are very robust with the amplitude of the cycle slightly increasing in μ.

When the interaction between agents is sufficiently strong, i.e. $\beta > 1/\delta(0)$, the system admits two additional equilibrium points. This is represented in Fig. 4, with P_2 standing as the case in which deniers prevail over changers, while P_3 corresponds to the opposite situation. Given that the capacity of adaptation of the productive structure is a positive function of m, this means that P_3 is a Pareto-superior solution in terms of economic prosperity. Analogously to the previous case, when the sufficient condition for local stability in Proposition 3 is satisfied, we observe monotonic convergence to one of the extreme equilibria, as in panel (a). Depending on initial conditions, an economy might end up either in P_2 or P_3. When $\beta = 2.5$, we have that $\mu_{HB} = 384.54$. Increasing the bifurcation parameter such that $\mu > \mu_{HB}$ leads to a super-critical Hopf bifurcation, leading to a limit cycle enclosing all three equilibrium points. Further increasing μ does not lead to the disappearance of the orbit, which proves to be very robust, as we can see in panels (c) and (d).[7]

Our model is able to reproduce a bi-modal distribution of countries or regions with the formation of two clubs of leader and laggard economies. This is in line with a well-known stylised fact in growth theory pointing to the divergent dynamics of countries (e.g. Dosi et al., 2020). Moreover, it provides a rationale for the so-called "kick-away-the-ladder" effect. That is, countries that happened to be at the top of the ladder typically preached the virtues of embracing competition and adopted a free-trade discourse, while those catching up, as they reached the top, also converted to such a position. We show that this will only happen as long as there is sufficient interaction among agents, a distinguishing feature of the world after the industrial revolution. Still, high interaction is not enough to guarantee sustained growth. The economy has to be able to learn and restructure, adapting fast enough as new goods, routines, and technologies are introduced. Thus, the capacity of adaption is endogenous to attitudes, which in turn are themselves endogenous to the productive structure.

Taking a closer look at the figures above, we can attempt to sketch a description of the dynamic interactions among institutional and technological change, as depicted in Fig. 5. The interplay between changers, neutrals, and deniers forms what we refer to as the collective opinion. Individuals reason and conceive reality as part of a collectivity, which allows them to express themselves. On the other hand, the latter is formed by single agents in a complex web of interactions in which the total is more than the sum of each part. As a consequence, institutions are a combination of written laws, formal rules, informal norms, and shared beliefs about the world sustained by a certain arrangement of behavioural dispositions. A given institutional setting, unique in its design, is associated with a certain capacity to

[7] The reader might wonder how realistic it is to assume such high values for μ. While there is certainly room for a deeper assessment of this issue, our understanding is that, as a first approximation, the assumption is quite reasonable. When $\beta = 2$ and $\mu_{HB} = 200$, an increase of 0.01 in the long-run rate of growth gives us $p^C \approx 0.5$ and $p^D \approx 0$. Analogously, a reduction of 0.01 in g results in $p^C \approx 0$ and $p^D \approx 0.5$. Under zero growth variation, $p^C \approx p^D \approx 0.25$. On the other hand, when $\beta = 2.5$ and $\mu_{HB} = 384$, we also obtain that $\dot{g} = 0.01$ results in $p^C \approx 0.5$ and $p^D \approx 0$. However, under $\dot{g} = 0$, it follows that $p^C \approx 0.4$ while $p^D \approx 0.1$.

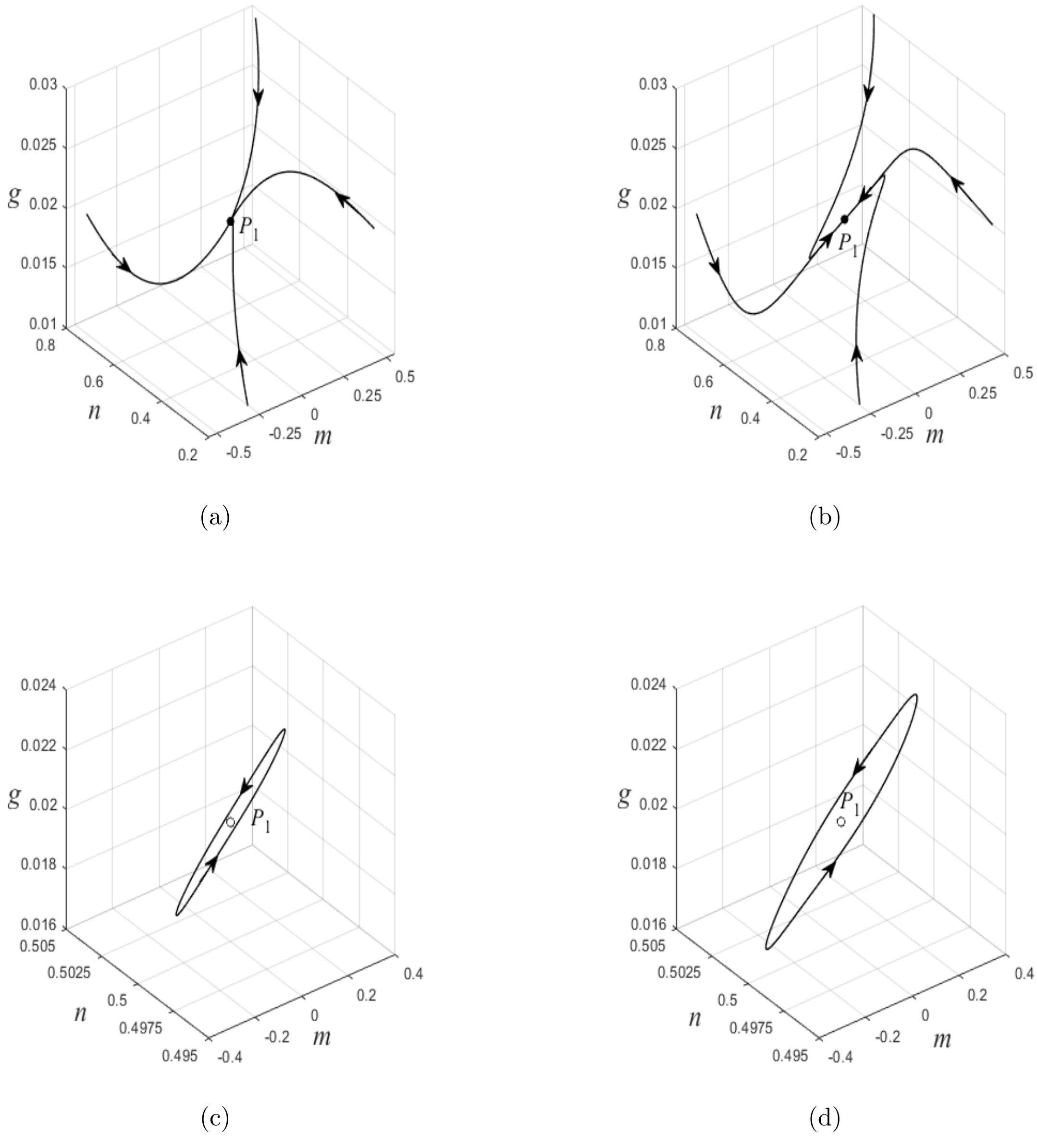


Figure 3: Different trajectories showing (a) monotonic convergence, $\beta = 0.75, \mu = 120$; (b) fluctuations of decreasing amplitude, $\beta = 2, \mu = 120$; (c) limit cycle, $\beta = 2, \mu = 225$; (d) robustness of the limit cycle, $\beta = 2, \mu = 275$.

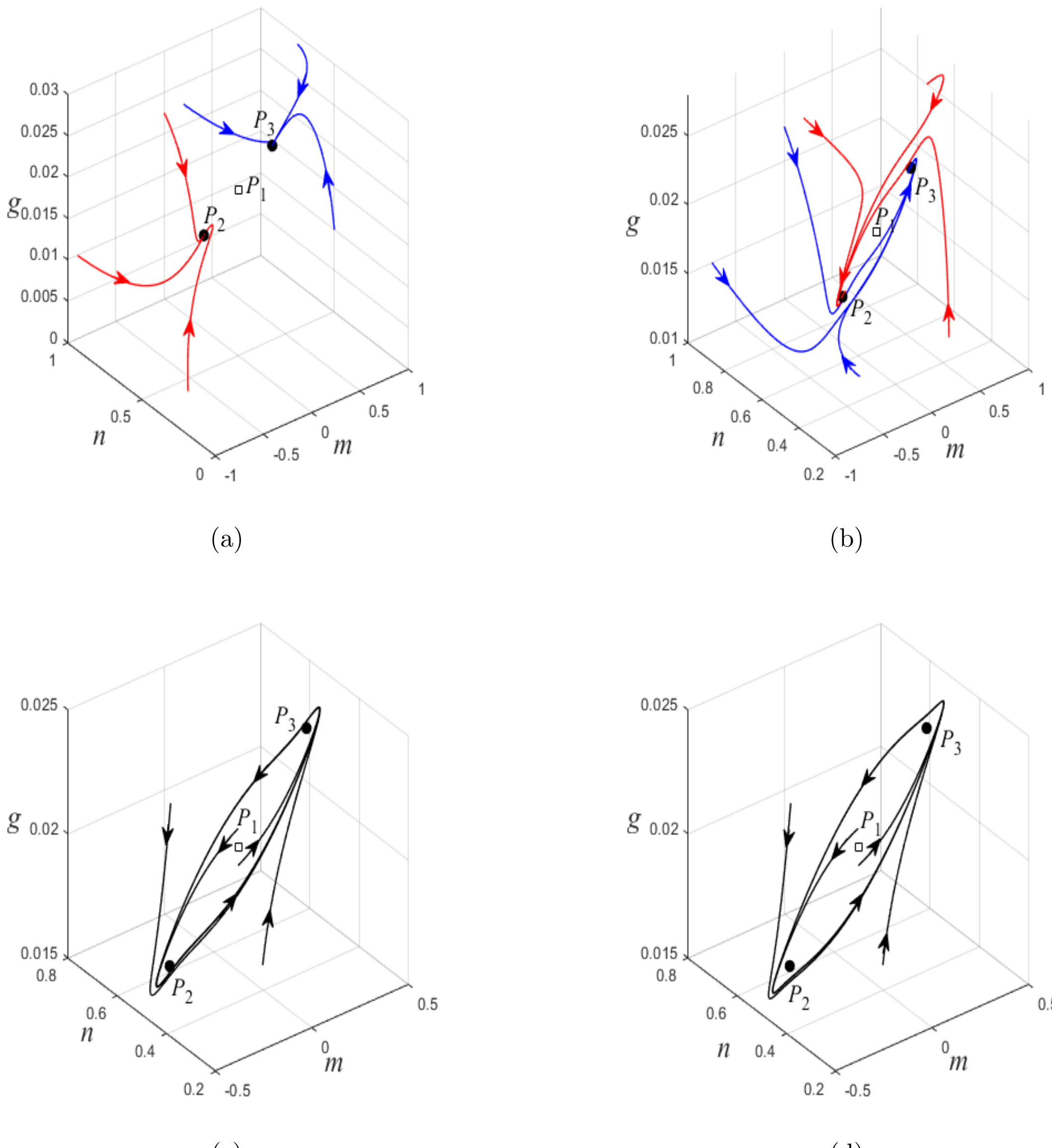


Figure 4: Different trajectories showing convergence to the equilibrium solutions for (a) $\mu = 120$, (b) $\mu = 300$; and convergence to the limit cycle for (c) $\mu = 390$, (d) $\mu = 600$, when $\beta = 2.5$.

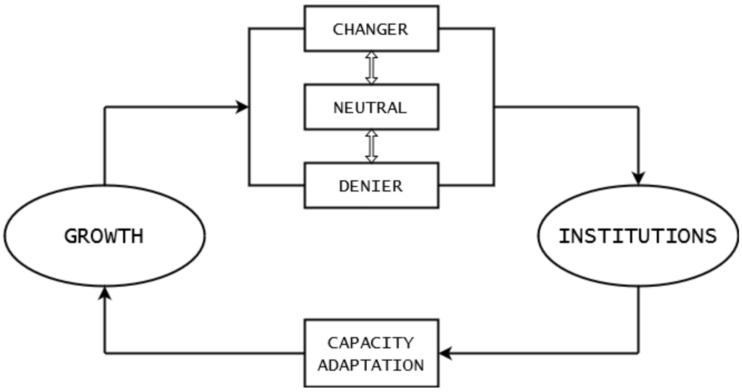


Figure 5: Summarising diagram.

adapt to the challenges imposed by innovative change. Economic growth becomes a subproduct of the pace at which past innovation leads to the adoption of new technologies and routines. It influences the probabilities of switching between dispositions, closing the loop from technology to institutions.

An increase in the share of changers in society leads to institutional adjustments compatible with a greater capacity of adaptation. This in turn results in a higher long-run rate of growth. As growth accelerates, people perceive the fruits of new technologies. The probability of adopting negative and neutral dispositions falls, while individuals become prone to welcome change. Such explosive dynamics characterise a virtuous and dynamic process of cumulative causation both on technological and institutional grounds:

$$L^C \uparrow \Rightarrow m \uparrow \Rightarrow \alpha \uparrow \Rightarrow g \uparrow \Rightarrow L^C \uparrow$$

Their counterpart lies in the endogenous spontaneous stabilisers inside the population. The number of changers, by definition, is limited to $0 < L^C < \bar{L}$. As changers approach the demographic ceiling, there is actually an increase in the pool of those who can potentially become neutrals. This means that, at a certain point, the number of indifferent dispositions will start to grow also increasing the share of deniers. As m starts to fall, the institutional set-up adjusts accordingly, this time reducing the capacity of adaptation of the economy. Economic growth decelerates, resulting in an increase in the probability of being a denier. A slow process of falling behind begins, with society gradually closing itself off to change and growing less in a cumulative way:

$$L^D \uparrow \Rightarrow m \downarrow \Rightarrow \alpha \downarrow \Rightarrow g \downarrow \Rightarrow L^D \uparrow$$

Such dynamics will continue until L^D approaches its own demographic ceiling. At this point, the cycle restarts.

The coexistence of two stable equilibrium solutions requires a careful investigation of the correspondent basin of attraction. This is done through a series of numerical experiments that provide further insights into the feasibility of changing from one attracting region to the other. While it is quite obvious that the stable manifold of the saddle P_1 determines the separatrix between the two locally stable equilibrium points, Fig. 6 shows that its shape changes as we increase the sensitivity of agents to growth. We depict in red all initial conditions that converge to P_2, and in blue those that lead to P_3. The system thus admits an additional representation of path dependence. Let us suppose an economy such that

$(g_0, m_0, n_0) = (0.025, -0.5, 0.5)$. When $\mu = 325$, there is convergence to the Pareto-superior solution, as in panels (a)-(b). However, when $\mu = 334.5$, P_2 becomes the relevant attractor, as we can see in panels (e)-(f). Hence, conditional upon μ, similar starting points might lead to a completely different equilibrium.

A numerical investigation of the basin of attraction also reveals the birth of a hidden periodic orbit. Contrary to self-excited oscillations, its attracting set in the phase space does not intersect with small neighbourhoods of any equilibria (for a review, see Leonov and Kuznetsov, 2013; an application to the Lorenz system can be found in Kuznetsov et al., 2020). In the interval $335.6 < \mu < \mu_{HB}$, initial conditions very close to P_2 and P_3 continue to converge to the respective equilibrium points. Still, Fig. 7 clearly distinguishes, in grey, the region for which trajectories go to the hidden periodic attractor. After the Hopf bifurcation, the resulting limit cycles are stable and merge with the previous orbit.[8]

The economic interpretation of both hidden and classical persistent fluctuations is similar: they bring a dynamic representation of a long-run process of cumulative causation. Nonetheless, we would like to point out that Fig. 7 comes with an extra flavour. A hidden cycle of structural and institutional change may coexist with locally stable fixed points. Important insights into this phenomenon have been provided by historians in recent decades and it has implications for the use of standard econometric techniques. The empirical literature on institutional economics is heavily grounded on the idea that different attractors might even coexist but should be locally stable. By demonstrating the presence of a hidden orbit, our model suggests that we should be careful in the interpretation of linear estimators, keeping in mind that the boundaries between equilibria are sensitive to the structure of the economic system.

5 Final considerations

This article developed a small-scale agent-based model to study how the institutional framework is transformed and reinforces technological change in a cumulative way as the productive structure evolves. Using data from the last two waves of the WVS, we made the case that societies that are more open to change are likely to find better ways to adapt to change. Acknowledging the concept of behavioural "dispositions", we differentiated between three types of agents: *changers*, *neutrals*, and *deniers*. The composition of the population was determined through a mechanism that resembles the well-known Logit dynamics, such that institutions and technological change are endogenous to each other.

As the degree of interaction between agents is increased, a Pitchfork bifurcation occurs giving rise to two different basins of attraction: one around an equilibrium with the majority of the population supporting innovation, and another with most agents being suspicious of change. The model indicates that neutral agents play an important role as an element of resilience. Conditional upon their share in equilibrium, an increase in the response of the respective probability functions to growth results in a super-critical Hopf-bifurcation, followed by the emergence of persistent fluctuations. The long-run cycles we obtain suggest

[8] The numerical localisation and study of hidden attractors might be quite challenging given that there is no possibility of using information about equilibria in the standard computational procedure. We noticed that at $\mu \approx 335.6$ the *MLE* becomes positive, indicating sensitivity to initial conditions. The positiveness of the largest Lyapunov exponent is often considered as an indication of chaotic behaviour. Nonetheless, one should be warned that in several cases this may not be true (e.g. Leonov and Kuznetsov, 2007). Indeed, it is easy to see that in our model the hidden attractor is periodic, though the frequency of the resulting orbits depends on the initial conditions.

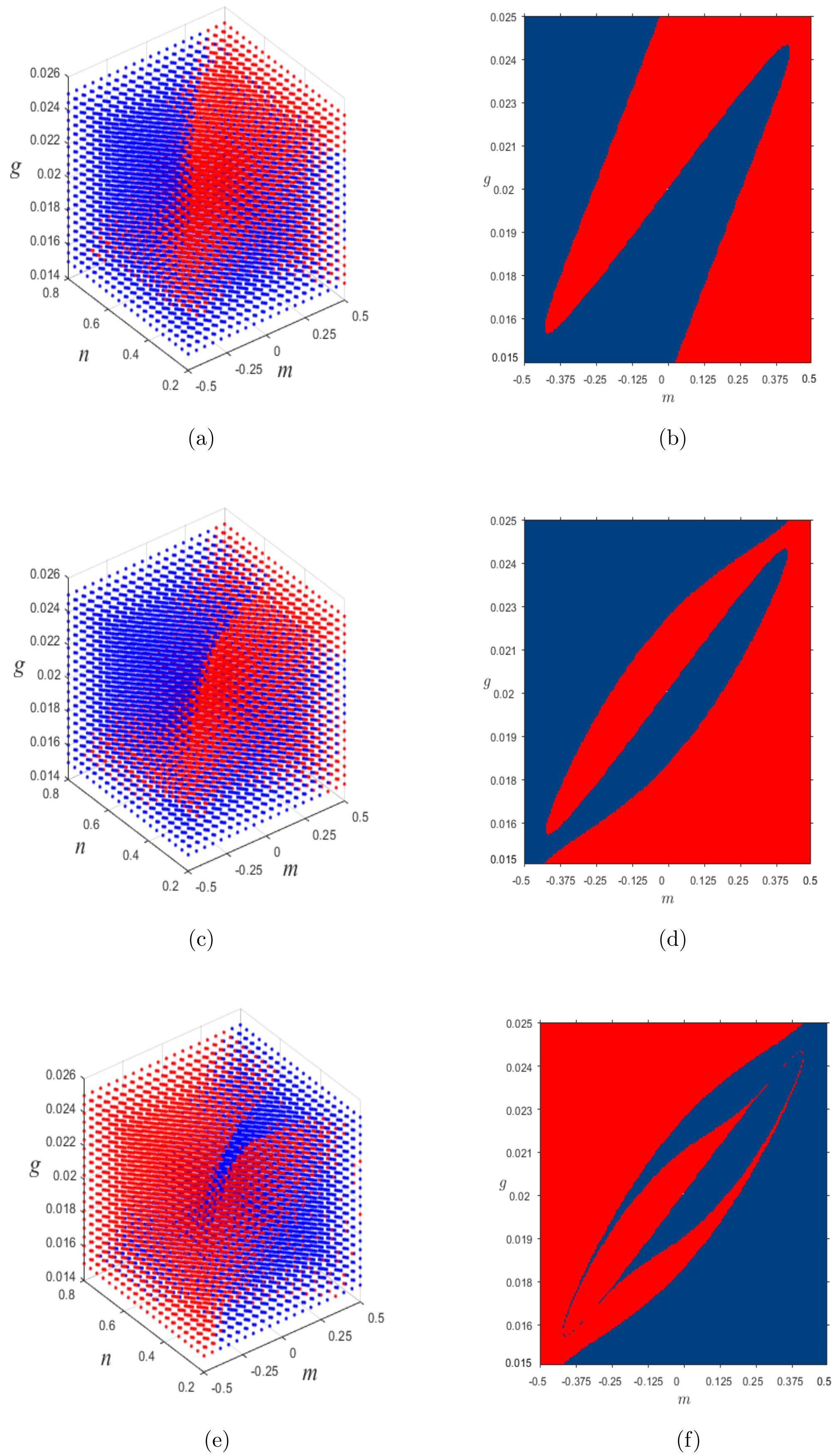
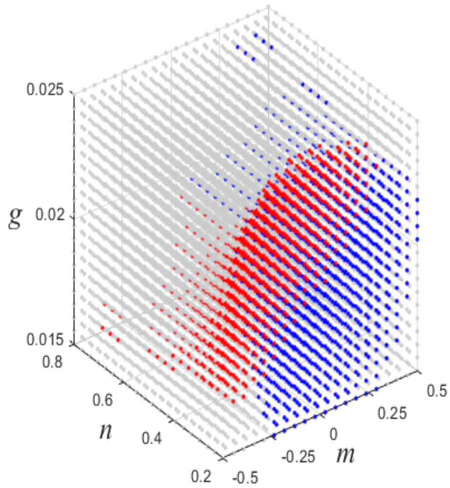
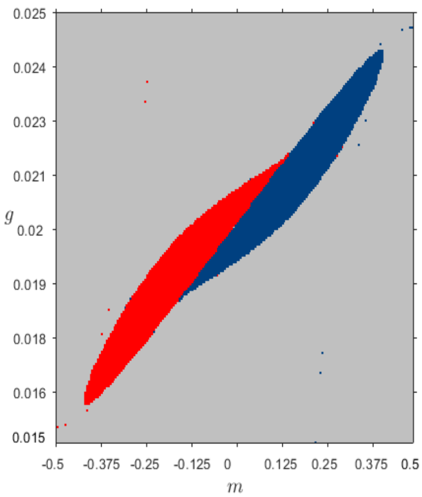


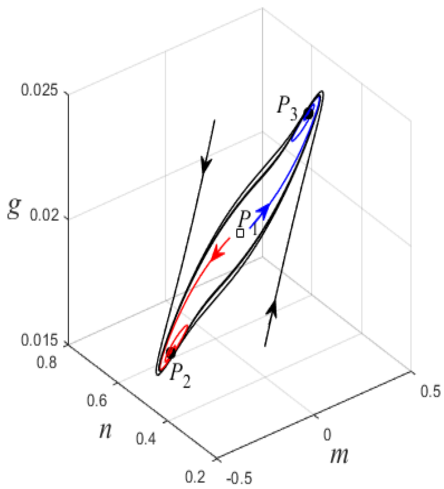
Figure 6: Basin of attraction in 3D when $\mu = 325$, panels (a) and (b); $\mu = 332$, panels (c) and (d); $\mu = 334.5$, panels (e) and (f). 2D projections are such that $n_0 = 0.5$



(a)



(b)



(c)

Figure 7: Basin of attraction and coexistence of attractors when $\mu = 336$.

that economies are more likely to be path-dependent than conventional approaches usually admit (see, for example, Franke, 2001).

There are important differences between public policies, which change regularly, and the governance of structures, which tend to change slowly. While all adjustments and disequilibrium dynamics in this paper regard the long-run, we believe our exercise comes with two important implications for the understanding of institutional design. First, there has to be enough interaction between individuals for the existence of a more desirable high-growth equilibrium. In this respect, the emergence of the so-called "filter bubbles" might increase polarisation and lead to the consolidation of institutional arrangements less friendly to innovative change. Second, a low-growth equilibrium trap might be the result of either a very low or a very high share of neutral agents in the population. Reforms aimed at reducing polarisation, in the former case, and at increasing political engagement, in the latter, may prove to be instrumentally useful.

Our model is able to reproduce a bi-modal distribution of countries such that there is the formation of two clubs of leader and laggard economies. This is in line with a well-known stylised fact in macroeconomics and deeply related to the literature trying to identify "windows of opportunity" for development. We also provided a complementary explanation of the so-called "kick-away-the-ladder" effect. Countries that happened to be at the top of the ladder typically preached the virtues of embracing competition and adopted a free-trade discourse, while those catching up, as they reached the top, also converted to such a position. In any case, we highlight that both institutions and technological change are endogenous to each other and context-dependent.

A major question that was only marginally discussed here concerns the nature of technical change. There are large differences between labour-enabling and labour-replacing technologies in terms of their impact on behavioural dispositions towards innovation. Future research on the topic is to be encouraged, perhaps exploring the potential links with the distribution of wealth and power in society.

A Empirical appendix

The WVS is the largest non-commercial cross-national empirical time-series investigation of human beliefs and values ever executed. We rely on the last two waves which cover the periods 2010-2014 and 2017-2020, respectively. Figs. 1 and 2 are based on data from the following countries:

- Both WVS 6 & 7: Argentina (ARG), Australia (AUS), Brazil (BRA), Chile (CHL), China (CHN), Taiwan (ROC), Colombia (COL), Cyprus (CYP), Ecuador (ECU), Germany (DEU), Iraq (IRQ), Japan (JPN), Kazakhstan (KAZ), Jordan (JOR), South Korea (KOR), Kyrgyzstan (KGZ), Lebanon (LBN), Malaysia (MYS), Mexico (MEX), New Zealand (NZL), Nigeria (NGA), Pakistan (PAK), Peru (PER), Philippines (PHL), Romania (ROU), Russia (RUS), Zimbabwe (ZWE), Thailand (THA), Tunisia (TUN), Turkey (TUR), Egypt (EGY), United States (USA), Uruguay (URY).

- Only WVS 6: Algeria (DZA), Azerbaijan (AZE), Armenia (ARM), Belarus (BLR), Estonia (EST), Georgia (GEO), Ghana (GHA), Haiti (HTI), Hong Kong (HKG), India (IND), Kuwait (KWT), Libya (LBY), Morocco (MAR), Netherlands (NLD), Poland (POL), Qatar (QAT), Rwanda (RWA), Singapore (SGP), Slovenia (SVN), South Africa

(ZAF), Spain (ESP), Sweden (SWE), Trinidad and Tobago (TTO), Ukraine (UKR), Uruguay (URY), Uzbekistan (UZB), Yemen (YEM).

- Only WVS 7: Andorra (AND), Bangladesh (BGD), Bolivia (BOL), Myanmar (MMR), Ethiopia (ETH), Greece (GRC), Guatemala (GTM), Hong Kong (HKG), Indonesia (IDN), Iran (IRN), Macau (MAC), Nicaragua (NIC), Puerto Rico (PRI), Serbia (SRB), Vietnam (VNM), Tajikistan (TJK).

We removed from our analysis countries that have experienced a negative average rate of growth over the past 10 or 20 years. This was done to avoid the extreme effects resulting from military conflicts, UN interventions, and prolonged economic recessions. Countries excluded are: Greece, Jordan, Kuwait, Lebanon, Qatar, Trinidad and Tobago, Haiti, Zimbabwe, and Yemen.

B Mathematical appendix

B.1 Proof of Proposition 1

Recall that in equilibrium:

$$\bar{g} = \alpha(\bar{m}) \tag{B.1}$$
$$\bar{n}\delta(0)\tanh(\beta\bar{m}) = \bar{m}[1-\delta(0)] \tag{B.2}$$
$$1-\delta(0) = \bar{n} \tag{B.3}$$

Substituting Eq. (B.3) into (B.2), we have:

$$[1-\delta(0)]\,\delta(0)\tanh(\beta\bar{m}) = \bar{m}[1-\delta(0)]$$

where $0 < \delta(0) < 1$. Hence, it follows that:

$$\tanh(\beta\bar{m}) = \frac{\bar{m}}{\delta(0)}$$

Graphically, Fig. B1 shows that:

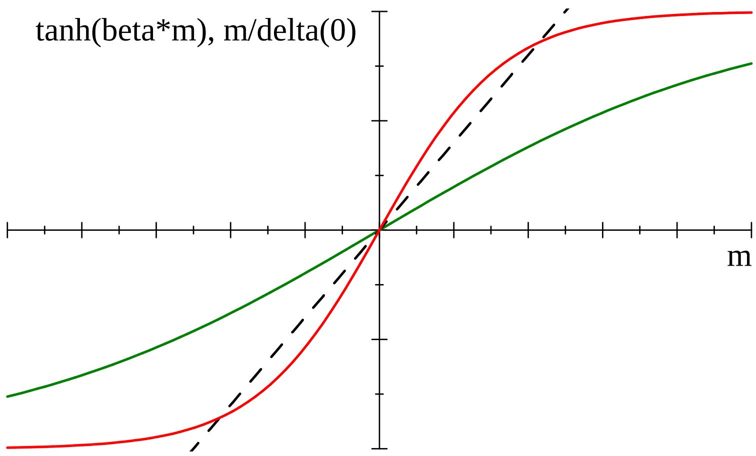


Figure B1: Determination of $\bar{m}$

where (i) the dotted line has a slope $1/\delta(0)$; (ii) the green line has a slope $1-\tanh^2(\beta m)$ with $\beta < 1/\delta(0)$; (iii) the red line has a slope $1-\tanh^2(\beta m)$ with $\beta > 1/\delta(0)$. The green curve only intercepts the dotted line in $\bar{m}_1 = 0$ while the red curve intercepts it in two extra points, $\bar{m}_2 < 0$ and $\bar{m}_3 > 0$.

Hence, making use of Eq. (B.1), when $\beta \leq 1/\delta(0)$, the dynamic system admits a unique equilibrium solution:

$$P_1 = (\bar{g}_1, \bar{m}_1, \bar{n}_1) = (\alpha(0), 0, 1-\delta(0))$$

On the other hand, when the "group effect" is sufficiently strong, i.e. $\beta > 1/\delta(0)$, two additional equilibria emerge:

$$\begin{aligned} P_2 &= (\bar{g}_2, \bar{m}_2, \bar{n}_2) = (\alpha(\bar{m}_2), \bar{m}_2, 1-\delta(0)) \\ P_3 &= (\bar{g}_3, \bar{m}_3, \bar{n}_3) = (\alpha(\bar{m}_3), \bar{m}_3, 1-\delta(0)) \end{aligned}$$

B.2 Proof of Proposition 2

Linearising the dynamic system around the equilibrium point $P_1 = (\bar{g}_1, \bar{m}_1, \bar{n}_1) = (\alpha(0), 0, 1-\delta(0))$, we obtain:

$$\begin{bmatrix} \dot{g} \\ \dot{m} \\ \dot{n} \end{bmatrix} = \underbrace{\begin{bmatrix} j_{11} & j_{12} & j_{13} \\ j_{21} & j_{22} & j_{23} \\ j_{31} & j_{32} & j_{33} \end{bmatrix}}_{\mathbf{J}|_{P_1}} \begin{bmatrix} g-\bar{g} \\ m-\bar{m} \\ n-\bar{n} \end{bmatrix}$$

where

$$\begin{aligned}
j_{11} &= \left.\frac{\partial h_1(g,m,n)}{\partial g}\right|_{P_1} = -\varepsilon < 0 \\
j_{12} &= \left.\frac{\partial h_1(g,m,n)}{\partial m}\right|_{P_1} = \varepsilon\alpha'(\bar{m}_1) = \varepsilon\alpha'(0) > 0 \\
j_{13} &= \left.\frac{\partial h_1(g,m,n)}{\partial n}\right|_{P_1} = 0 \\
j_{21} &= \left.\frac{\partial h_2(g,m,n)}{\partial g}\right|_{P_1} = -\bar{n}_1\delta(0)\beta\mu\varepsilon < 0 \\
j_{22} &= \left.\frac{\partial h_2(g,m,n)}{\partial m}\right|_{P_1} \\
&= \bar{n}_1\delta'(0)\varepsilon\alpha'(\bar{m}_1)\tanh(\beta\bar{m}_1) + \bar{n}_1\delta(0)\beta\left[1+\mu\varepsilon\alpha'(\bar{m}_1)\right] \\
&\quad -\left[1-\delta(0)\right] + \bar{m}_1\delta'(0)\varepsilon\alpha'(\bar{m}_1) \\
&= -\bar{n}_1\left\{1-\delta(0)\beta\left[1+\mu\varepsilon\alpha'(0)\right]\right\} \gtreqless 0 \\
j_{23} &= \left.\frac{\partial h_2(g,m,n)}{\partial n}\right|_{P_1} = 0 \\
j_{31} &= \left.\frac{\partial h_3(g,m,n)}{\partial g}\right|_{P_1} = \delta'(0)\varepsilon = 0 \\
j_{32} &= \left.\frac{\partial h_3(g,m,n)}{\partial m}\right|_{P_1} = -\delta'(0)\varepsilon\alpha'(0) = 0 \\
j_{33} &= \left.\frac{\partial h_3(g,m,n)}{\partial n}\right|_{P_1} = -1 < 0
\end{aligned}$$

so that

$$
\begin{aligned}
\left|\mathbf{J}|_{P_1}-\lambda\mathbf{I}\right| &= \begin{vmatrix} -\varepsilon-\lambda & j_{12} & 0 \\ j_{21} & j_{22}-\lambda & 0 \\ 0 & 0 & -1-\lambda \end{vmatrix} \\
&= -(1+\lambda)\begin{vmatrix} -\varepsilon-\lambda & j_{12} \\ j_{21} & j_{22}-\lambda \end{vmatrix} \\
&= -(1+\lambda)\left[\lambda^2-(-\varepsilon+j_{22})\lambda-\varepsilon j_{22}-j_{12}j_{21}\right]=0
\end{aligned}
$$

Thus, one of the characteristic roots is $\lambda_1=-1$, whereas the other two are found by solving

$$\lambda^2-(-\varepsilon+j_{22})\lambda-\varepsilon j_{22}-j_{12}j_{21}=0$$

When condition (24) is satisfied, we have

$$1-\delta(0)\beta[1+\mu\varepsilon\alpha'(0)]>0$$

and therefore

$$j_{22}<0$$

In this case, the succession of sign of the characteristic equation is $+++$ so that λ_2 and λ_3 are negative real numbers when $\Delta>0$, whereas they are complex conjugate with negative real part when $\Delta<0$. We can then conclude that P_1 is locally stable.

Furthermore, notice that λ_2 and λ_3 become purely imaginary when $-\varepsilon+j_{22}=0$, a case that occurs when μ takes the value

$$\mu_{HB}=\frac{\varepsilon+\bar{n}_1[1-\delta(0)\beta]}{\bar{n}_1\delta(0)\beta\varepsilon\alpha'(0)}$$

such that

$$\left.\frac{d\left(\frac{-\varepsilon+j_{22}}{2}\right)}{d\mu}\right|_{\mu=\mu_{HB}}=\frac{\bar{n}_1\delta(0)\beta\varepsilon\alpha'(0)}{2}>0$$

This proves the existence in this case of *periodic solutions*.

B.3 Proof of Proposition 3

When $\beta>1/\delta(0)$, at $P_1=(\bar{g}_1,\bar{m}_1,\bar{n}_1)=(\alpha(0),0,1-\delta(0))$, all elements of the Jacobian matrix are the same as in the previous case, with the only difference that now j_{22} is always positive:

$$j_{22}=-\bar{n}_1\underbrace{\{1-\delta(0)\beta[1+\mu\varepsilon\alpha'(0)]\}}_{<0}>0$$

It is then still true that $\lambda_1=-1$, whereas with regard to the other two roots,

$$
\begin{aligned}
\lambda_{2,3} &= \frac{1}{2}\left\{-\varepsilon+j_{22}\pm\sqrt{(-\varepsilon+j_{22})^2-4(-\varepsilon j_{22}-j_{12}j_{21})}\right\} \\
&= \frac{1}{2}\left\{-\varepsilon+j_{22}\pm\sqrt{\Delta}\right\},
\end{aligned}
$$

we now have

$$\begin{aligned} -\varepsilon j_{22} - j_{12}j_{21} &= \varepsilon \bar{n}_1 \left\{1 - \delta(0)\beta\left[1 + \mu\varepsilon\alpha'(0)\right]\right\} + \varepsilon\alpha'(0)\bar{n}_1\delta(0)\beta\mu\varepsilon \\ &= \varepsilon\bar{n}_1 - \varepsilon\bar{n}_1\delta(0)\beta - \varepsilon\bar{n}_1\delta(0)\beta\mu\varepsilon\alpha'(0) + \varepsilon\alpha'(0)\bar{n}_1\delta(0)\beta\mu\varepsilon \\ &= \varepsilon\bar{n}_1\left[1 - \delta(0)\beta\right] < 0 \end{aligned}$$

Thus, $\Delta > 0$, implying that the two roots λ_2 and λ_3 are real and of opposite sign. The equilibrium point P_1 is therefore a *saddle point.*

At $P_i = (\bar{g}_i, \bar{m}_i, \bar{n}_i) = (\alpha(\bar{m}_i), \bar{m}_i, 1 - \delta(0))$, where $i = 2, 3$, we have

$$\begin{aligned} j_{12} &= \left.\frac{\partial h_1(g,m)}{\partial m}\right|_{P_i} = \varepsilon\alpha'(\bar{m}_i) > 0 \\ j_{21} &= \left.\frac{\partial h_2(g,m,n)}{\partial g}\right|_{P_i} = -\bar{n}_i\delta(0)\beta\mu\varepsilon\left[1 - \tanh^2(\beta\bar{m}_i)\right] = -\bar{n}_i\delta(0)\beta\mu\varepsilon F_i < 0 \\ j_{22} &= \left.\frac{\partial h_2(g,m,n)}{\partial m}\right|_{P_i} = -\bar{n}_i\left\{1 - \delta(0)\beta\left[1 + \mu\varepsilon\alpha'(\bar{m}_i)\right]\left[1 - \tanh^2(\beta\bar{m}_i)\right]\right\} \\ &= -\bar{n}_i\left\{1 - \delta(0)\beta\left[1 + \mu\varepsilon\alpha'(\bar{m}_i)\right]F_i\right\} \gtreqless 0 \\ j_{23} &= \left.\frac{\partial h_2(g,m,n)}{\partial n}\right|_{P_i} = \delta(0)\tanh(\beta\bar{m}_i) > 0 \end{aligned}$$

so that

$$\begin{aligned} \left|\mathbf{J}|_{P_i} - \lambda\mathbf{I}\right| &= \begin{vmatrix} -\varepsilon - \lambda & j_{12} & 0 \\ j_{21} & j_{22} - \lambda & j_{23} \\ 0 & 0 & -1 - \lambda \end{vmatrix} \\ &= -(1+\lambda)\begin{vmatrix} -\varepsilon - \lambda & j_{12} \\ j_{21} & j_{22} - \lambda \end{vmatrix} \\ &= -(1+\lambda)\left[\lambda^2 - (-\varepsilon + j_{22})\lambda - \varepsilon j_{22} - j_{12}j_{21}\right] = 0 \end{aligned}$$

Thus, one of the characteristic roots is $\lambda_1 = -1$, whereas the other two are found by solving

$$\lambda^2 - (-\varepsilon + j_{22})\lambda - \varepsilon j_{22} - j_{12}j_{21} = 0$$

When condition (25) is satisfied, we have

$$1 - \delta(0)\beta\left[1 + \varepsilon\alpha'(m_i)\mu\right]F_i > 0$$

and therefore

$$j_{22} < 0$$

so that

$$-\varepsilon j_{22} - j_{12}j_{21} > 0$$

In this case, the succession of sign of the characteristic equation is $+++$ and therefore the two roots λ_2 and λ_3 are real and negative when $\Delta > 0$, whereas they are complex conjugate with negative real part when $\Delta < 0$. We can then conclude that P_2 and P_3 are either *locally stable nodes* or *locally stable foci.*

Furthermore, notice that λ_2 and λ_3 become purely imaginary when $-\varepsilon + j_{22} = 0$, a case that occurs when μ takes the value

$$\mu_{HB} = \frac{\varepsilon + \bar{n}_i \left[1 - \delta(0)\beta F_i\right]}{\bar{n}_i \delta(0)\beta\varepsilon\alpha'(\bar{m}_i) F_i}$$

such that

$$\left.\frac{d\left(\frac{-\varepsilon + j_{22}}{2}\right)}{d\mu}\right|_{\mu=\mu_{HB}} = \frac{\bar{n}_i \delta(0)\beta\varepsilon\alpha'(0) F_i}{2} > 0$$

This proves the existence in this case of *periodic solutions.*

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