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The political economy of complexity: The case of cyber-communism

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ABSTRACT

This article analyzes cyber-communism and the feasibility of central planning from complexity theory. It first introduces the most known definitions of complexity in economics, namely computational and dynamic complexity. This enables to construct a complexity political economy from which then deal with cyber-communism. This political economy highlights the notion of *cultivation*, as a natural selection approach to established successful institutions and rules. In contrast to cultivation, the article presents the notion of *control*, which corresponds to traditional political economy, as the belief in the effective alteration of economic variables by a group of planners or policymakers. This work emphasizes some problems central planning faces: self-reference, noncomputability of optimal points, reflexivity, and less adaptive capacity. It concludes that cyber-communism conflicts with a complexity political economy based on cultivation, and that cyber-communist planning is not realistic, ultimately meaning that technology cannot allow and effective socialist planning.

1. Introduction

In recent decades, several authors have argued that economics is experiencing a paradigm shift (Beinhocker, 2007; Colander et al., 2004; Holt et al., 2011; Potts, 2000). Traditional economics, represented by neoclassical economics, is being gradually replaced by a new economic perspective, usually called *complexity* economics. This new paradigm is made up of many ideas from heterodox schools (behavioral, experimental, evolutionary, post-Keynesian, Austrian, and institutionalism), and uses more realistic assumptions than those simplistic assumptions of traditional economics (Potts, 2000).

Complexity came to economics by applying the latest innovations in systems theory from physics, math, and biology. In this sense, complexity conceived the economy out of equilibrium, portraying it as "process dependent, organic, and always evolving" rather than "deterministic, predictable, and mechanistic" (Arthur, 1999, p. 109). Generally, it could be said that, contrary to neoclassical economics, complexity economics rejects traditional assumptions such as decreasing returns,

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perfect rationality, or static equilibrium while emphasizing increasing returns, bounded rationality, learning, or evolution (Wible, 2000).

In speaking of complexity, it is also important to mention computer science. In economics, although a complexity approach or even an algorithmic representation of theory does not necessarily depend on a physical computer (Arthur, 2021a), computation and simulations have gone hand in hand with complexity economics (Mirowski, 2001; Roth, 2002; Tesfatsion and Judd, 2006). Agent-based modeling, which is a field related to complexity economics (Arthur, 2021a), developed thanks to advances in computer technology during the eighties and early nineties (Hoefman, 2020). This reflects how advances in technology open new possibilities to economics and any other science. As a result of these new possibilities, economists have elaborated new models and forms of doing economics and finance (Axtell and Farmer, 2021) or even novel approaches to public policy (Colander and Kupers, 2014). Modern computing has also led some researchers to revisit historical debates looking for novel interpretations that might change the debates' conclusions. This is precisely the case of cyber-communism and the socialist calculation debate.

Cottrell and Cockshott (1993) revisited the historical socialist calculation debate in light of an alternative socialist theory and the latest developments in the technology of computation of that time. According to those theorists, the economic calculation problem set out by Mises (2012, 1998) and the knowledge problem enunciated by Hayek (1945)**,** stating, on the one hand, that the rational allocation of resources is not possible without private property of the means of production and, on the other hand, that knowledge in the economy cannot be given to or processed by a single mind, appeared old-fashioned due to the vast computation capacity achieved by new technology. They thus concluded that an effective socialist planning system is possible thanks to modern computing. Currently, these authors and their followers (Cockshott, 2017; Cockshott and Nieto, 2017; Nieto, 2020; Nieto and Mateo, 2020) refer to information and communication technologies (ICTs), such as Big Data, Artificial Intelligence, machine learning, and the internet of things, as tools easing data processing and, in turn, the establishment of a cybernetically planned communist system. They have called it "cyber-communism": a social planning system without private property rights over the means of production operating through information and communication technologies (ICTs). The promise of cyber communism implies: (a) rational calculation in terms of labor time supplemented by currently computational power to promote the efficient real-time allocation of economic resources (Mises's objection), and (b) individuals choosing their consumption preferences and collective decisions made democratically, resolving the complexity problem of the use of knowledge in society (Hayek's objection).

Although cyber-communist authors directly refer to the computability of socialist planning, a complexity related issue, we argue that socialist planning precisely faces a non-computability problem, among other issues. Given the critical role that information and communication technologies (ICT) play in economic and social life, understanding their epistemic frontiers is an essential inquiry for economic theory and political economy. In this paper, we shall question the feasibility of cyber communism from a complexity perspective[1]. We will do so because one of the main arguments of cyber-communism is that current technology makes economic calculation computable, which involves both computational and dynamic complexity arguments. Consequently, we will argue that it is impossible to control economic and social complexity, stressing that the problem of economic planning without private property rights does not lie in a technological issue but in epistemic and ontological concerns related to nature of complex adaptive systems. Thus, we will first present the computational and dynamic complexity definitions, which are the most used in economics. This will be dealt in Section 2. Section 3 will outline the implications of complexity theory for political economy, endorsing a political economy based on *cultivation* instead of *control*. In this way, we construct a theoretical framework from which to analyze the cyber-communist proposal, which we develop in Section 4. Section 5 draws the conclusions of our article.

2. Two definitions of complexity: computational and dynamic

As an emerging discipline, complexity economics has different definitions (Arthur et al., 1997; Arthur, 2021b; Hoefman, 2020; Rosser, 1999, 2009a; Wible, 2000). A comprehensive complexity theory does not exist yet. However, there are specific interpretations more widespread than others. Following Simon (1991), *complexity* can be defined at a general level as the study of systems displaying nonsimple relationships between their parts. Roughly speaking, complexity theory realizes that, in a system, the whole is more than the sum or aggregation of the individual parts. In economics, complexity can be understood as a discipline that involves the interaction of economic variables under the assumption of abandoning equilibrium (Arthur, 2021b). The systematic research on complexity economics can even be traced back to the era before

[1] As we shall see below in the article, several complexity arguments overlap previous Austrian thesis from Ludwig von Mises, Friedrich A. Hayek, or Donald Lavoie. This is not a mere coincidence, given that the complexity current consists of heterodox theories, as we remarked above in the introduction. There are two reasons why we address cyber-communism from complexity economics rather than Austrian economics itself. First, cyber-communist authors ultimately base their argument on computability, which is a complexity question. Austrian theory relies more on economic logic than on complexity or computation reasons, although it can be interpreted from a complexity perspective (Koppl, 2009; Velupillai, 2000). We believe that a computational/complexity theory such as cyber-communism is better rebutted in computational/complexity terms than on economic grounds. Second, complexity, as composed of various heterodox schools, offers a broader perspective than Austrian economics. In this way, not only Austrians are involved in a new round of the socialist calculation debate, but also other schools such as institutionalism, behavioral, experimental, evolutionary economics, and even Marxian economics. A broader perspective can enrich the discussion beyond traditional arguments. What is more, by adopting a complexity perspective, the socialist calculation debate can be seen as more than a conflict between two schools of thought: Austrian versus socialists. With complexity, the socialist calculation debate can now be seen as a clash between two paradigms: traditional versus complexity economics.

Adam Smith's classical economics (Colander, 2000). At that time, economists were already exploring trade patterns, market prices and quantities of goods produced and consumed, individual behavior, and the economic aggregate outcomes of these behaviors. These topics are also the scope of modern complexity economics' research.

The complexity movement originated in Brussels, Ann Arbor, and Stuttgart in the 1970s, laying the foundations for modern complex economic research (Rosser, 1999). Complexity believes that the objects studied by complex systems should include variables involving natural sciences (such as biological cells) and social sciences (such as automobiles). This field studies how these individual elements, interacting in a system, create overall patterns and how these patterns, in turn, cause the elements to change or adapt in response (Arthur, 2021b). In economics, the application of complexity theory began at the Santa Fe Institute in the late 1980s. Since the 1990s, these phenomena have been gradually explored from different definitions of complexity in economics. The two most common definitions of complexity in economics are *computational* complexity and *dynamic* complexity (Rosser, 2009b).

The term computational complexity has several uses. On the one hand, it refers to an algorithm solving cases of a problem, being computational complexity the measure of how many steps the algorithm needs, in the worst case, for computing an input of a given size. The number of steps is measured according to the size of the input. On the other hand, computational complexity can also refer to the very problem that an algorithm tries to solve. Thus, computational complexity theory focuses on classifying problems according to their inherent difficulty, namely, whether they are difficult or easy to solve. To determine this difficulty, one must consider the resources the solution to the problem requires, such as time and memory, regardless of the algorithm used. Moreover, computational complexity research also seeks to determine whether the problem is effectively computable or not, that is, where the limits of computation are.

The origin of computational complexity traces back to the Church-Turing thesis, at the beginning of the twentieth century. This thesis shows the equivalence of two separately developed theories, Alan Turing's (1937) argument on the one hand, and Alonzo Church's (1936) thesis on the other hand. They both demonstrate that a universal decision procedure is not possible in mathematics, thus setting the limits of computation (Immerman, 2018). The application of computational complexity theory to economics is ultimately based on the Church-Turing thesis (Rosser, 2009b). Its principal proponent is Vela Velupillai (2000), who coined the term *computable economics*.

Additionally, computable economics is also founded on the algorithmic complexity theory of Kolmogorov, Solomonoff and Chaitin (Chaitin, 1987; Kolmogorov, 1983, 1968), which states that complexity can be measured according to the algorithmic information contained, to the size of the shortest algorithm generating the number of elements being studied (Rosser, 2009b). Therefore, computable economics looks at the economy from an algorithmic perspective: objects, agents, interactions, institutions, and even the market itself are considered algorithms (Mirowski, 2007). Computable economics research has studied the computability of important parts of standard economic theory, concluding that many of them are not computable in any sense. These are, for example, Walrasian equilibria (Lewis, 1992), Nash equilibria (Tsuji et al., 1998), or general aspects of macroeconomics (Leijonhufvud, 1993).

In contrast to the well-defined measures of computational complexity, dynamic complexity is defined in a negative way. Following Day (1994), J. Barkley Rosser Jr., as the major proponent of the dynamic complexity approach, asserts: "a dynamical system is complex if it endogenously does not tend asymptotically to a fixed point, a limit cycle, or an explosion" (Rosser, 1999, p. 170). Put it differently, a dynamical system does not endogenously and deterministically generate concrete, well-behaved outcomes (Rosser, 2009b). Just as computational complexity has its roots in the Church-Turing and Kolmogorov-Solomonoff-Chaitin theses, the predecessors of dynamic complexity are nonlinear dynamics such as cybernetics, catastrophe theory, and chaos theory (Rosser, 1999).

Barkley Rosser Jr. argues that his concept of dynamic complexity constitutes a broad tent definition encompassing cybernetics, catastrophe theory, chaos theory, and also, the most recognized conception of complexity in economics, namely an agent-based complexity known as the Santa Fe complexity. This definition appeared from the meetings at the Santa Fe Institute in the late 1980s. According to it, the economy is seen as a Complex Adaptive System (CAS), whose characteristics are, following Arthur et al. (1997): (1) dispersed interaction among heterogeneous agents; (2) there is no global controller able to exploit all opportunities or interactions in the system, rather control takes place in a small scale through cooperation and competition mechanisms among agents; (3) there are many levels of cross-cutting hierarchical interactions and organization; (4) the system continually adapts as agents accumulate experience and learning, revising their strategies and behavior; (5) perpetual novelty as new niches (markets, technologies, institutions, or behaviors) cause the appearance of other new niches; and (6) out-of-equilibrium dynamics since new niches and possibilities are continually appearing, being the system unlikely to be near a global optimum.

Systems with these properties can also be called *adaptive nonlinear networks*, as John Holland called them. There are many examples of them: nervous systems, ecologies, immune systems and, of course, economies (Arthur et al., 1997). All these systems exhibit discontinuous and nonlinear behavior, making predictability and model-building even harder tasks, thus prompting the use of concepts such as *emergence* or *self-organization*.

The concept of emergence refers to the process by which a higher level in a system may originate from a lower level in complexity. All definitions of emergence imply a hierarchical system with higher and lower levels, macroscopic and microscopic. Roughly speaking, we can say that biology focuses on emergent phenomena from chemistry –life emerges from nonliving substances— or psychology studies emergent phenomena from neurobiology. Similarly, matter, society, or the economy constitute systems resulting from emergent processes (Wible, 2000). The term dates back to Greek philosophers such as Aristotle. However, complexity theory has taken the concept of emergence as an analogy of biological phenomena such as *anagenesis*, which has been used to represent market processes such as economic development or the evolution of economic institutions (Rosser, 2012).

Emergence is closely related to self-organization. In affirming that a system emerges or evolves, one assumes that the system is not planned or controlled in any conscious sense. As we have just remarked, a complex system operates through decentralized mechanisms of cooperation and competition rather than directed by a global controller. Therefore, since a controller does not direct the economy, it can be concluded that it self-organizes; it reproduces, decreases, grows, and evolves itself.

Models developed from this perspective of complexity, combining computation, emergence, and self-organization, have made it possible to study increasing returns and path-dependencies in technological lock-in contexts (Arthur, 1994, 1989), persistent divergences in national economic growth rates (Durlauf, 1996), bubble chaotic dynamics in financial markets (Brock and Hommes, 1997), spatial trading networks (Kirman, 1997), and much more. All these models have expanded our knowledge of economic processes. Most importantly, they have enabled us to reach richer conclusions beyond standard economics.

Indeed, complexity economics contrasts with traditional, neoclassical economics. In a recent paper, Arthur (2021b) gathers the main differences between both approaches. On the one hand, neoclassical economics emphasizes resource allocation under given conditions. It reduces acting people and changing agents to the *homo economicus* representative agent, assuming perfect rationality and common knowledge. Moreover, traditional economics portrays the economy in equilibrium, as if it worked like a clockwork mechanism. Thus, any change in the economy is conceived as a shift between two equilibrium points. Besides that, as economic problems are well-defined and agents possess perfect rationality and common knowledge, the inevitable condition of uncertainty disappears.

Contrariwise, complexity economics holds that the economy is not always in a state of equilibrium. Neither economic agents are entirely rational nor possess common knowledge. Therefore, the economic system itself is not seen as a machine working perfectly in an equilibrium world. Instead, the economy is a constantly changing ecology of beliefs, organizing principles, and behaviors. Complexity emphasizes emergence, bounded rationality, evolution and change, uncertainty, and novelty. It represents a new way of doing economics, aiming at a more realistic understanding of economic phenomena.

3. Implications of complexity for political economy: cultivation and control

The appearance of complexity theory in economic science constitutes a new way of doing economics that can impact all its disciplines. As a field of economics, political economy is not less affected by complexity theory than other branches such as methodology or modeling. Thus, it may be of interest to rethink political economy from a complexity approach.

Colander and Kupers (2014) argue that traditional political economy discussions can be understood as a debate between two groups: free-market advocates – *leave it to the market*—or economics of control advocates – *the government will solve the problem*—. They hold that this simplistic distinction is a byproduct of the standard model: the neoclassical paradigm. From a complexity perspective, it is erroneous to conceive political economy in such a confronted and simplistic manner. Neither can any government control a complex system, nor does it play any role in the economy since it is a natural element of the complex system itself. The complexity frame looks at political economy differently.

In light of the new complexity view of science, Donald Lavoie (1989) points out that political economy should be oriented toward *cultivation* rather than *control*. By control, Lavoie means the power to manage the functioning of an economy and refers to an analogy of an engineer able to manage a machine and predict its particular outcomes with certainty. As we addressed in section 2, complexity sees the economy not as a machine or a clockwork mechanism, but as an emergent order with unpredictable outcomes; as a Complex Adaptive System (CAS) (Markose, 2005). Therefore, no one can control an economy and its behavior, as if it were a machine (Colander and Kupers, 2014). This applies equally to central planning, economics of control, and to more orthodox, traditional political economy advocating minimal intervention or even *laissez faire*. This is because even minimal intervention advocates have usually assumed that, although the government cannot control the entire economy, is indeed able to effectively manipulate certain parameters according to estimates by policymakers. This is control too, although to a lesser extent than central planning, which represents absolute control.

As several authors have shown from computational complexity (da Costa and Doria, 1994; Koppl, 2010, 2008; Markose, 2005; Tsuji et al., 1998; van den Hauwe, 2011; Velupillai, 2000), central planning (absolute control) is not possible given the noncomputability of the equilibria of an economy (Tsuji et al., 1998), being the calculation of equilibrium prices even regarded as a NP-hard problem[2] (van den Hauwe, 2011). The reason of this impossibility can be found in a self-reference problem, which Koppl (2010, 2008), Markose (2005), van den Hauwe (2011), and Velupillai (2000) have highlighted by using Hayek's (1952) connectionist theory of mind. This theory states that the mind cannot fully explain its own operations since "any apparatus of classification must possess a structure of higher degree of complexity than is possessed by the objects which it classifies; and that, therefore, the capacity of any explaining agent must be limited to objects with a structure possessing a degree of complexity lower than its own" (Hayek, 1952, p. 185). This logic parallels Cantor's (1984) di-

[2] A NP-hard problem is a mathematical problem with no smart algorithm leading to a rapid or simple solution. The only way to reach an optimal solution is to intensively compute and test all possible outcomes (van den Hauwe, 2011).

agonal proof[3] and Gödel's (1992) incompleteness theorems[4], and applied to central planning means that a central planner cannot either fully know an economy containing the central plan within it, due a self-reference issue (Rosser, 2012).

From dynamic complexity, central planning seems to be already excluded by the very use of terms such as *emergence, self-organization,* or *spontaneous order* (Rosser, 2009b). Nonetheless, before elaborating further our argument, it is worth noting that a complexity perspective does not *necessarily* imply a rejection of central planning or small control. As we will show in the next section, this explains why cyber-communist authors, despite based on a branch of complexity theory, defend the feasibility of central planning. Or even why some recognized authors from the Santa Fe Institute such as John Holland believe in small interventions to exert some control over complex systems (Holland, 2002). It is one thing to say that a CAS operates through decentralized mechanisms rather than driven by a global controller (Arthur et al., 1997), and another to derive from that description an impossibility principle about central planning. What we find here is that conclusions about central planning can depend on the complexity approach adopted and on the conceptualization of ideas such as control or intervention. One can see in complexity theory a better understanding of the world thus enabling to control it better. Contrariwise, from our perspective, we start asserting that central planning is not feasible and argue that, given complexity science, it follows more consistently to reject the traditional notions of control and intervention and advocate the *cultivation* metaphor, which we are about to explain. Moreover, although one complexity theorist supports some kind of small control, we believe the *cultivation* metaphor can be likewise presented as a dominant theme over *control* for this economist.

Returning to our discussion, we want to emphasize that the same logic behind the impossibility of central planning or absolute control applies to orthodox political economy. Neoclassical economics has generally assumed that markets are efficient, so they can work without government intervention. Yet, most traditional economics has also recognized the fallibility of markets in some occasions (Beinhocker, 2007), which are usually identified as market failures. In these cases, the government is expected to correct the market so that the outcome can be Pareto optimal (Musgrave, 1939; Samuelson, 1947). Even more, self-proclaimed advocates of *laissez faire,* such as many Chicago school economists, believe that organizations such as a central bank, that is, another kind of central planning organism in the field of money, should *control* the supply of money and credit in complex economies to avoid depressions. In this way, traditional economics assumes that the government is able to control the economy to a certain degree, to manage not all but certain variables and alter them to get expected and desirable outcomes. This, additionally, presupposes the existence of a Pareto optimum; an efficient allocation of recourses in an equilibrium point. As shown, this clashes with a complexity perspective, since the economy cannot be controlled or altered to achieve predictable outcomes, and there is no such a thing as a globally optimal point from a complexity perspective.

Given that control is incompatible with a complexity vision – at least as we understand it, Lavoie (1989) proposes complexity political economy to be based on what he calls *cultivation*. The term *cultivation* was coined by Hayek (1955, p. 225) and derived from the idea that any theory about complex phenomena can only provide an explanation of the principle, a general pattern description[5], instead of a complete, concrete, and particular explanation or pattern description. This is a direct consequence of his connectionist theory of the mind (Hayek, 1952) and, as shown above, applies to the *control* problem. Hayek employed *cultivation* in the sense "in which the farmer or gardener cultivates plants, where he knows and can control only some of the determining circumstances" (Hayek, 1955, p. 225). Applied to an economy, cultivating refers to the protection of institutions. Here, institutions are described as "socially constructed invariants that provide the actors who participate in them with the means and resources to cope with change and diversity" (Mirowski, 1988, p. 132). These include habits, rules, routines, paradigms, and conventions (Choi, 1993; Hodgson, 1988; Rutherford, 2004); in short, the rules of the game (Hayek, 1973; Langlois, 1992). Ultimately, the outcome in a system emerges from the dispersed interaction among agents coordinated through institutions.

A political economy based on *cultivation* rather than *control* brings particular attention to institutions (see Table 1 for a summary of the differences between traditional political economy and a complexity political economy). Institutions such as money or property rights are rules, which can even be seen as algorithms[6] (Velupillai, 2000), emerged in co-evolution with the economic system, that enable agents to coordinate. They output new information, feeding the algorithmic functioning of

[3] Cantor's (1984) theorem shows through its diagonal proof that the set of real numbers is uncountable since there are infinite sets that cannot correspond one to one with the infinite set of natural numbers. In this sense, Hayek's (1952) argument appealed to a diagonal logic similar to Cantor's to argue that mind cannot self-descript itself (Koppl and Rosser, 2002). Thus, Hayek's diagonal proof can be regarded as a direct consequence of Cantor's theorem, as Koppl (2010) demonstrates.

[4] Gödel's (1992) incompleteness theorems, based on a diagonal argument, state that: (1) any consistent formal system encompassing elementary arithmetic is always incomplete, given that there are sentences that cannot be proved or disproved in the formalism; and (2) that any consistent formal system *F*, containing elementary arithmetic, cannot arithmetically prove the consistency of *F*. Consequently, Gödel himself affirmed: "the human mind is incapable of formulating (or mechanizing) all its mathematical intuitions" (Wang, 2016, p. 324). This assertion is quite similar to Hayek's (1952) theory, and Hayek himself noted it.

[5] After explaining why mind cannot fully know itself, Hayek (1952) argued that the best we can hope for is an *explanation of the principle*; a general explanation of mental processes. The same applies to social phenomena, so Hayek (1967) would refer to *pattern predictions.* These are general, qualitative, trend predictions about economic phenomena, as opposed to concrete or quantitative predictions of economic events.

[6] As one reviewer of this article has accurately pointed out, the economy can be viewed algorithmically, but it is equally important to recognize that non-algorithmic processes play a very important role to solve certain non-computable problems. Although not a crucial point, this remark deserves special attention in this article since one of our claims is that cyber-communism faces a computability problem.

Table 1
Differences between traditional and complexity political economy.

Feature	Traditional political economy	Complexity political economy
Organizing principle	Equilibrium. The economy is seen from a static viewpoint.	Nonequilibrium, recursiveness, process, and emergence.
Metaphor	Machine: the economy is conceived as a vast clockwork mechanism.	Ecology: the economy is a spontaneous order, subject to evolution in a non-deterministic way, as in biology.
Dominant theme	*Control:* economists are like mechanics or engineers.	*Cultivation:* economists are like farmers or gardeners.
Focus	Quantitative parameters	Institutions and agent interactions
Central planning	Feasible	Unfeasible
Government	Strong intervention in the market. Any macro government action is expected to be effective.	From a coevolutionary, polycentric or micro role to a minimal or even null role. Depending on the political characterization of government.

the economy, and contributing in turn to its emergence. In this sense, to see the economy as a complex evolving system and the focus on institutions lead to a political economy from the bottom-up, rather than from the top-down. This translates into a *complexity* political economy recognizing that the economy works thanks to emergent and self-organizing dynamics among dispersed individuals, thus giving the government a different role compared to traditional political economy. For a complexity political economy, the government should not impose and act coercively –*control*— because this would undermine the economy's emergent processes and self-organizing dynamics. Instead, the government should influence to encourage voluntary, spontaneous coordination among individuals –*cultivation*— (Colander and Kupers, 2014).

Previous authors such as Hayek (1960) or Ostrom (2010), both sharing a complexity approach to economics, advocated *cultivation*. On the one hand, Hayek believed in a minimal government that creates the conditions from which economic outcomes can emerge (Hayek, 1960); a government protecting the *spontaneous order*, rather than intervening it (Hayek, 1982). On the other hand, although she does not employ the term *cultivation,* Ostrom (2010) elaborated a *polycentric approach*, which portrays the role of the government in a complex system as distributed across multiple interacting levels of rules and decision making (Colander and Kupers, 2014). Furthermore, similar approaches to complexity economics, such as *entangled political economy* (Wagner, 2021, 2014), draw analogous conclusions about the role of government (Devereaux, 2021). This means that, from complexity political economy, the role of government can vary depending on the conceptualization of government, provided that it does not attempt to control the economy but cultivate or influence its institutions[7].

Having described how a complexity political economy would be, compared to traditional political economy, one could now wonder: what are the differences between the complexity political economy focused on cultivation and the long tradition of free-market economics, especially Austrian economics? Why develop a complexity political economy if we can use free-market economics or Austrian political economy, which have proven to be considerably similar to complexity?

First, it cannot be denied that the complexity political economy laid out in this paper is heavily influenced by Austrian economics. This should come as no surprise, given that, as we mentioned above, complexity economics is formed by the influence of a wide variety of heterodox economic currents (Potts, 2000). The term cultivation, for example, was coined by Hayek (1955), and then employed by Lavoie (1989), two Austrian economists. However, complexity political economy is not limited to Austrian economics but is open to all heterodox economic currents that shape complexity economics. Hence, any scholar can approach complexity political economy without being necessarily Austrian. For instance, Colander, Kupers, or Ostrom are not Austrian economists, despite having many overlapping ideas with Austrian economics, and provide two insightful models for a complexity political economy. This, as we remarked in footnote 1, allows to construct a political economy with ideas from behavioral, institutional, evolutionary, post Keynesian, experimental, or even Marxian economics, in addition to purely Austrian theories. The complexity political economy can thus appeal more scholars beyond Austrian economics, or even beyond the economic discipline itself, since complexity requires interdisciplinary work (physicists, computer scientists, or biologists). This makes it possible to develop a richer and more complete perspective than if it was limited to a single school of thought such as Austrian economics.

Furthermore, as Colander and Kupers (2014) say, a complexity political economy deviates from what they call *Classical laissez faire* and *free-market fundamentalism*. On the one hand, Classical laissez faire (Adam Smith, John Stuart Mill, as Colander and Kupers name) assumes that the government can effectively control certain parameters in an economy, while complexity economics rejects this idea and believe that the government should focus on influencing and cultivating institutions. On the other hand, free-market fundamentalism (Milton Friedman, George Stigler) refuses government intervention since it believes, from a general equilibrium model, that the market can achieve efficiency without needing the government.

[7] This opens a possibility for the development of many diverse approaches to complexity political economy. Hayek, Ostrom, Wagner, Colander, or Kupers believe that the government is a naturally emerged actor in a complex system, and thus a symbiosis is possible between the market and the government. However, one can adopt a different political view of government, such as a libertarian (Nozick, 1974) or an anarcho-capitalist (Rothbard, 2006, 1998) political philosophy. For many libertarians and anarcho-capitalists, the government is not a natural, emerged actor in a complex system, but a rational, consciously designed organization directed by a group of people. Its mere existence violates eminent market institutions such as private property rights (Rothbard, 2006, 1998). Therefore, there cannot be any symbiotic relationship between the market and the government. In this case, the role of government inevitably becomes almost absent or even null.

Contrariwise, complexity can see the government as another natural actor of a complex evolving system and challenges the idea of the market alone achieving full efficiency, given that complexity neglects the existence of global optima. Hence, complexity political economy constitutes an alternative approach to traditional laissez faire or some free-market economics and allows a comprehensive perspective beyond Austrian economics.

4. The case of cyber-communism

The reason why we have addressed complexity and its political economy in this article is none other than deal with cyber-communism. As we shall see below, cyber-communism is presented as a complexity-based theory, referring to computation, algorithmic, and information theory. Further, it is more than an economic theory; it constitutes a political economy, given that it is focused on maximizing people's well-being and proposes an alternative social organization. Therefore, a complexity political economy allows us to analyze cyber-communism from both complexity-related abstract grounds, and a political economy perspective.

As we mentioned in the introduction, cyber-communism theory argues that socialist planning is currently possible thanks to information and communication technologies (ICTs) such as Big Data, Artificial Intelligence, or machine learning (Cockshott, 2017; Cockshott and Nieto, 2017; Cottrell and Cockshott, 1993). Indeed, cyber-communist authors consider that, at the time of the socialist calculation debate [see Bergson (1948), Samuelson (1948), and Schumpeter (2006) for a standard account of the debate. See Lavoie (1985), and Boettke (2000) for an Austrian, revised version], there was a problem of technological insufficiency to efficiently plan an increasingly complex economy requiring control of increasing volumes of information. Hence, cyber-communists concede that Austrian economists were right and also that, afterward, "there was never an effective and well-elaborated response to the Austrian approach" (Nieto, 2020, p. 132). However, they also assert that the Austrian arguments are now outdated because technological development and advances in computation processing enable socialist calculation (Cockshott and Cottrell, 1997a; Cottrell and Cockshott, 1993), and thus attempt to end the historical socialist calculation debate with a victory for socialists.

If the cyber-communist argument were just that, it would not be so different from Lange's (1967) proposal for the use of computers to carry out economic calculation. Yet, cyber-communism differs from past neoclassical socialists in that it is based on labor theory of value rather than subjective value theory. According to Cottrell and Cockshott (1993), this is one of the elements that makes socialist planning possible. Indeed, Cottrell and Cockshott (2007) admit that neoclassical equilibrium is unattainable by socialist planning, given that computing equilibrium prices is NP-hard, in line with other previously cited authors in this paper (da Costa and Doria, 1994; Koppl, 2010, 2008; Markose, 2005; Tsuji et al., 1998; van den Hauwe, 2011; Velupillai, 2000). However, as we have just noted, cyber-communism is based on labor theory of value and also dispenses the neoclassical notion of mechanical equilibrium, replacing it with their *statistical equilibrium*, which Cottrell and Cockshott take from Farjoun and Machover (1983). This equilibrium is not conceived as a point in phase space, but as a region defined by particular macroscopic variables, in that there is a huge set of microscopic conditions compatible with it. Hence, cyber-communists see socialist planning as tractable, and even more efficient than the market (Cottrell and Cockshott, 2007).

According to Cockshott and Cottrell (1997b, 1989; 1993), labor time can be used as an objectively recognizable unit of value to conduct socialist planning. They argue that the fundamental allocation problem corresponding to a pattern of production is the allocation of available productive labor in different activities. Most inputs can be expressed in their labor content, then labor time is the ultimate resource available (Cockshott and Cottrell, 1989). Moreover, they respond to some critiques of the use of labor time such as those from Mises (1935) regarding nonreproducible goods and the inhomogeneity of labor. For nonreproducible goods, Cottrell and Cockshott (1993) say that the problem does not solve itself under capitalism and that the possible solutions can come through two ways. First, by charging the cost of research into the production of substitutes to the resource-consuming industries of nonreproducible goods. And second, through democratic debate about specific technologies or projects. For the inhomogeneity of labor, the authors propose to treat skilled labor as a produced input transferring embodied labor to its product over time, as Marx (1976) did with the means of production. They also propose to grade skilled labor into different productivity levels. Therefore, it is reasonable to express economic planning in terms of labor time, cyber-communist authors suggest.

Additionally, Cottrell and Cockshott (1993) show that economic calculation in labor time is possible in light of the state of modern computing through an iterative method solving a linear input-output system in which production conditions are presented. Increasing mathematical techniques of linear programming would allow the calculation of the labor time and the optimal allocation of resources in real-time. In fact, Nieto (2020), and Nieto and Mateo (2020) note that some of these possibilities are already present in the operations of large leading companies through the application of new information technologies, such as Facebook, Amazon, Spotify, and Netflix (Phillips and Rozworski, 2019). Cottrell and Cockshott (2007) go even further and prove through a quantitative measure, following Chaitin's (1987) information theory, that the amount of information to transmit in a planned system with labor values is considerably lower than that conveyed by prices in a market system. With this, they affirm to debunk Hayek's (1945) claims that centralization of information is not possible or at least more onerous than decentralized transmission of information, and contend that centralization of information is more efficient in computational terms (Cockshott and Cottrell, 1997a; Cottrell and Cockshott, 2007). Following the Church-Turing thesis (Church, 1936; Turing, 1937), if a problem can be solved by a dispersed number of human computers, then it can also be solved by a Universal Computer, which means that if it is computable by distributed humans, it is likewise computable by a planning agency's computers (Cottrell and Cockshott, 2007). This, of course, does not mean that decentralized, local knowledge is not relevant. Contrariwise, Cockshott and Cottrell see no contradiction between a central plan and the use of local knowledge. It is not necessary that a central plan stipulates which workers are best at which specific tasks in a firm. This can be decided at each layer of the organization, just as large multi-plant capitalist enterprises do not plan it centrally but leave the decision be made at the plant level (Cockshott and Cottrell, 1997a).

Once central planning has been regarded as reasonable and feasible through labor value, what only remains is to match production, the central plan, and a pattern of social needs or consumer choices. To put it simply: match supply and demand. "Demand" can be revealed through both democratic political decisions and aggregate consumer purchases (Cockshott and Cottrell, 1989). For the latter, Cottrell and Cockshott (1993) present a "consumer goods algorithm" whereby consumer choice can determine the allocation of labor time to the production of personal consumption goods. In this sense, they assert that feedback is essential, so that the plan can dynamically adapt to fast changes in social demands (Cockshott and Cottrell, 1989).

In this way, Cottrell and Cockshott (1992) outline a socialist system without private ownership of the means of production, where:

(1) A planning bureau computes and determines a central economic plan through labor time values.
(2) State-owned firms follow instructions from the planners and send information about their technical input coefficients and output stocks, as well as about consumer choices.
(3) Typical market institutions are displaced by democratic institutions. Capitalist-entrepreneurs are replaced by a combination of expert opinion and democratic methods.
(4) Instead of money, there are labor certificates that allow to set a price for consumer goods.

4.1. Cyber-communism and complexity at the abstract level

At first, what cyber-communism suggests seems to deviate from complexity economics as described in Section 2. While complexity economics studies a CAS as a system of decentralized interaction without a global controller in which a global optimum is unlikely attainable due to the perpetual creation of new niches, cyber-communist authors such as Cottrell and Cockshott focus on a system governed by an effective global controller, and additionally, assume a type of *statistical* equilibrium – different from Walrasian equilibrium, and that global optimization of the whole economy is likely and feasible.

Despite these differences, these authors are also aligned with complexity theory; concretely, computational complexity. Cockshott and Cottrell base several of their arguments on fundamental computational complexity theories, which we mentioned in section 2: the Church-Turing thesis (Cottrell and Cockshott, 2007), Shannon's (1948) information theory (Cockshott and Cottrell, 1997a), and Chaitin's (1987) algorithmic information theory (Cottrell and Cockshott, 2007). Cottrell and Cockshott (1993) actually see the economy as a complex system. This appears to refute one of our main claims in this paper, which is that by holding a complexity view, it consistently follows that central planning is unfeasible and that control cannot be a fundamental metaphor for political economy. Yet, as we have just seen, cyber-communists draw on complexity theory and support the feasibility of central planning at the same time. Is our perspective capable of providing an explanation to this seemly contradictory position?

We may speculate that the answer to the question lies in the definition of complexity Cockshott and Cottrell hold. As we remarked in section 3, to support a complexity approach does not *necessarily* involve the rejection of central planning. We do contend, and this is what we want to convey to complexity theorists and economists through this article, that it is more consistent to reject central planning in view of complexity theory than to uphold it. However, one can likewise find authors such as Cockshott and Cottrell whose theory of central planning is founded on complexity theory. In this case, the reason why these authors believe in central planning lies in their adoption of a computational complexity view.

Despite present in economics through, for instance, computable economics (Velupillai, 2000), the computational approach is not predominant. Instead, dynamic complexity is the perspective most widely shared by economists (Rosser, 2012). The six defining features of the economy as a complex system named by Arthur et al. (1997) belong to the dynamic approach to complexity, not to the computational one. Moreover, there is a tendency from computational complexity authors to discredit dynamic complexity for being a vague definition with "empty" ideas such as *emergence*, in contrast to the well-defined and concrete foundations of computational complexity, such as algorithmic complexity or stochastic complexity (Rosser, 2009b). Hence, it is unsurprising that Cockshott and Cottrell do not approach the economy as a CAS, thus obviating the notion of *emergence* or nonalgorithmic processes which are key ideas when studying the feasibility of central planning, and instead focus on algorithmic computation and the optimization of the economy.

Nevertheless, we want to add that even for computational complexity, central planning can be regarded as unfeasible. In fact, Koppl and Rosser (2002) and Wolpert (2001) develop important arguments in light of computational complexity theory which affect the feasibility of central planning in economics. Koppl and Rosser (2002) study the problem of self-reference in economics and its impact on prediction and control, which we already mentioned in section 3. The main thesis is that self-reference can lead to unsolvable paradoxes in many economic contexts, as for example, the Holmes-Moriarty game designed by Morgenstern (1976). In this game, each actor possesses perfect rationality, namely, each of them knows what each and the other will do. This leads to a "I think that you think that I think that you think that I think...", which ultimately constitutes an inescapable paradox. If we now assume that each agent in the economy can be modeled as a Turning machine (Velupillai, 2000), it can be equally inferred that perfect foresight of others' behavior is unfeasible, because it leads to a paradox. In this case, agents as Turning machines will encounter a halting problem, they will never stop and spit out a value. With this, Koppl and Rosser (2002) go even further and adapt Wolpert's (2001) argument that imagines the problem to be solved as computable, solvable by any kind of computer: supercomputers, ordinary laptops, human beings, or even hypercomputers, if they were physically realizable. It can be interpreted, as Koppl and Rosser put it, as a sub-Turing world where every problem is computable. Note that this is a powerful theory since it establishes that limits to rationality exist aside from the model of rationality adopted, even if there are computers more powerful than Turing machines in this sub-Turing world. Therefore, the paradox now has nothing to do with computability, because we are in a computable context, but with the relative speed of predictions: they can be made, but not always ahead of time.

Wolpert (2001, p. 1) demonstrates that "the universe cannot contain a computer to which one can pose any arbitrary computational task". Any computer in the world can sometimes make mistakes about the world. Based on this idea, Wolpert shows that no computer in the world can predict everything about the world ahead of time. Therefore, no computer can process information faster than the universe. This is because the computer is within the system, in the world as well, not as a detached observer, thus facing a self-reference problem. Koppl and Rosser (2002, p. 358) apply Wolpert's theory to economics to highlight that econometricians, who may be compared to high-powered computers, cannot always process information faster than the economy. Econometricians trying to predict the future of the economy are trying to predict the results of a process driven by agents who are at least as sophisticated as the observing econometricians. They cannot consistently outperform agents of the observed economy by predicting ahead of time the results of economic processes.

Subsequently, Rosser (2012) has remarked elsewhere in a more synthetic way that a planning agency cannot fully know or control an economy containing the production plan within it. This translates into central planning is not feasible from algorithmic computational complexity[8] since there is the fundamental problem of self-reference.

When Cottrell and Cockshott (1993) assert that optimization in a complex system does not necessarily involve the arithmetic maximization of a scalar objective function but can be achieved through computation and simulation, they give an example of the operation of a neural control system, with the case of a butterfly in flight:

> A butterfly in flight has to control its thoracic muscles to direct its movement towards objects, fruit or flowers, that are likely to provide it with sources of energy. In so doing, it has to compute which of many possible wing movements are likely to bring it nearer to nectar. Different sequences of muscle movements have different costs in terms of energy consumption and bring different benefits in terms of nectar. The butterfly's nervous system has the task of optimizing with respect to these costs and benefits, using non-arithmetical methods of computation
>
> (Cottrell and Cockshott, 1993, p. 79).

The central point is that a control system requires the ability to compute, whether proceeding by arithmetical means or not. As they claim that the economy would have much in common with the operation of nervous systems, they believe that a global optimization of the whole economy is possible through computational techniques without even using arithmetic.

Nervous systems indeed compute, but, as Hayek (1952) explained, they do it across a decentralized structure of higher and lower parts or centers, which stand related through different orders with particular degrees of complexity, each computing a set of stimuli and responses. Therefore, one can find a hierarchy of orders, ranging from lower levels to higher levels of control. At the higher centers, connections are between classes of stimuli and classes of responses, and any order given in response to a situation may be a general direction for an action of a particular class. It is at the lower centers where the appropriate response is determined, following the higher centers directives, but giving particular and concrete orders. Hence, behavior results from an emergent process between the interaction of numerous control centers of higher and lower complexity. It cannot be determined by the sum or aggregation of the interconnections between the various centers. Neither can it be known ex-ante but only ex-post, once action has already taken place, due to the emergent relationships between classes of stimuli and classes of responses. Therefore, if the economy is to be understood as a nervous system, it must be clear that the economy's behavior cannot be given ex-ante; it cannot be planned or designed by a higher center; it needs to emerge.

With this same example of the nervous system, one can understand the problem of self-reference leading to noncomputability. The nervous system cannot fully explain its own operations not only because it does possess the same degree of complexity as its parts, but also because its operations take place through an emergent process, which self-organizes itself. In this sense, both the *emergentism* of computational and dynamic complexity can be combined to affirm that it is impossible to establish an effective economic plan ex-ante, before agents' interactions occur (Rosser, 2012).

Cyber-communist theory appears to assume that a control system is an independent part of the complex system itself, as it could control and compute all the system from without. It seems that the butterfly, as an entity independent from or at the highest level of its nervous system, could fully specify and control its behavior. As we have just shown, the complete

[8] It is noteworthy that we are speaking in terms of algorithmic computability, also called Turing computability. This is different from other approaches that believe in the feasibility of hypercomputation, meaning that hypercomputers could compute what is not Turing computable. There is no agreement among theorists on the feasibility of hypercomputation nonetheless (Da Costa and Doria, 2009). In fact, Paul Cockshott rejects hypercomputation (Cockshott et al., 2008), which means that cyber-communism is presented in terms of Turing computability and explains why we also speak of algorithmic computability. However, our arguments hold even considering the hypothetical feasibility of hypercomputers, as they include Koppl and Rosser's (2002) work, based on Wolpert's argument of a "sub-Turing world" where there is no noncomputable problem. As we have mentioned above, in this sub-Turing world the problem is not computability but the speed with which predictions are made.

control of any complex system is impossible, due to the problem of self-reference. The butterfly cannot completely explain its behavior, with all its underlying processes and interconnections. Similarly, no planning agency can define the behavior of an economic system beforehand. To this, the issue of reflexivity can be added, making it even harder to plan a system which the planner is within. That is, when planning, the planner should not only account for controlled agents' behavior in the system but also for his own behavior, given that, insofar as he/she is inside the system, he/she likewise conditions system's final behavior (Koppl, 2011).

Because of their computational complexity approach, cyber-communist theorists tend to contrast central planning and market/decentralized planning in terms of information processing. As mentioned above, Cottrell and Cockshott (2007) prove through a quantitative measure that the amount of information to transmit in a planned system with labor values is considerably lower than that conveyed by prices in a market system. With this, they contend that centralization of information is more efficient in computational terms (Cockshott and Cottrell, 1997a; Cottrell and Cockshott, 2007). If a problem can be solved by a dispersed number of human computers, then it can also be solved by a Universal Computer (Church, 1936; Turing, 1937), which means that if it is computable by distributed humans, it is likewise computable by a socialist planning agency's computers (Cottrell and Cockshott, 2007). Albeit true, this may not be the way complexity economics compares two economic systems. Traditional comparative economic systems analyze the market versus central planning according to an optimality criterion. Yet, complexity economics rejects the idea of a global optimum or equilibrium, and so two different economic systems cannot be judged by looking at which of them is able to achieve a superior global optimum or equilibrium point, or which is more efficient in static terms[9]. Instead, we propose an *adaptability* criterion for a complexity approach to comparative economic systems.

Thanks to John Holland, we know that systems are not only complex in that there are many dynamic interactions among parts and emergence; but most importantly, they are adaptive (Waldrop, 1992). This means that the parts do not have a fixed behavior but are able to process information, learn from the past, and modify their behavior according to changes in the environment as *agents*. That a species survives in the biosphere depends on its capacity to adapt to a changing environment. The same applies to a company or an economy, which are other two Complex Adaptive Systems (Beinhocker, 2007). Therefore, adaptation is fundamental for a dynamic vision of the universe, and is intrinsically linked to evolution and learning at the deepest level (Waldrop, 1992). In this sense, the adaptability criterion may mark the abstract superiority of a complex system, such as an economy, over another. An economic system would be superior to other if it possesses a better adaptive capacity: it is more likely that this system survives or even reproduces than one having less adaptive capacity.

In the market versus cyber-communism comparison, we contrast a decentralized system with a centralized one. Kauffman and Macready (1995) show that dispersed optimization of a highly interconnected landscape produced better global outcomes than a central optimization of the same landscape, which indicates that decentralized systems have a better adaptive capacity than centralized ones. Note that optimization here has a static connotation, given that these authors assume fixed technological fitness landscapes. If, as in reality, the economy changes and evolves, then the optimization problem becomes dynamic (Phelan, 2020), and we can expect the adaptive superiority of a decentralized system to turn even higher over a centralized one. Consequently, a market system, as a decentralized structure, can be considered superior to a cyber-communist model, which is a centralized system[10], according to the adaptability criterion based on complexity theory.

The focus on adaptation lies in the fact that any CAS is subject to perpetual novelty (Arthur et al., 1997; Waldrop, 1992). This amounts to saying, as Koppl et al. (2015) argue, that the economy is a creative process. New opportunities, new niches, are continually created in the adjacent possible. These niches, in turn, cause new possibilities (Cazzolla Gatti et al., 2020), so the economic process is creative because generates novelty itself. According to Koppl et al. (2015), this is an emphasis on emergence, which suggests a strong parallel between emergence in the biosphere and the econosphere. Along these lines, by applying evolutionary laws developed in the field of biology to economics, these authors conclude that due to the perpetual novelty and emergence of economic processes, there is no prestatable phase space in the econosphere, since it is subject to ever-lasting change. Therefore, the equations of motion of the ever-changing economy cannot be written down *ex ante*. We can only know them *ex post*, once they have occurred or, to put it in more accurate terms, *emerged*.

Although Cottrell and Cockshott reject neoclassical general equilibrium, they endorse a kind of *statistical equilibrium* applied to economics (Cottrell and Cockshott, 2007), so in a sense, they assume a knowable, pregiven phase space for the economy. This implies that all possible future goods or states are assumed to be mapped and estimated. Indeed, Cottrell and Cockshott (2007, p. 10) talk about the "phase space of possible economies", and regard it a part of the economic problem in a search for optimal points within a phase space as well. As discussed in the previous paragraph, a complexity-evolutionary view of the economy cannot assume a prestatable phase space, as it cannot be presupposed in biology. Still, central planning involves this very assumption: central planners should be able to map the possible future scenarios (phase space of pos-

[9] Buchanan and Vanberg (1991) uphold a creative view of economics, very much in line with complexity economics. They do not believe in general equilibrium or mere aggregate outcomes, but on emergence, complexity, and the creativeness of the economic process. From this viewpoint, they assert: "there simply is no 'external', independently defined objective against which the results of the market processes can be evaluated (…) then any idealized omniscience on the part of a planner who might attempt to duplicate the market result would become patently absurd" (pp. 181-182).

[10] We are aware that there are other socialist alternatives advocating decentralized planning, parallel to that of the market. These are known as, for instance, *participatory* planning (Adaman and Devine, 1996). As our work is concerned with cyber-communism, our conclusions limit to this model and do not aim to reach general implications for any socialist model. Therefore, addressing decentralized socialist systems is beyond the scope of this article, we just analyze a central planning proposal such as cyber-communism.

Table 2
Differences between cyber-communist political economy and complexity political economy.

Feature	Cyber-communist political economy	Complexity political economy
Organizing principle	Linearity and computation. Algorithmic view of the economy.	Nonequilibrium, recursiveness, process, and emergence.
Metaphor	Butterfly in flight. A control system can compute and optimize behavior or a system beyond arithmetic.	Ecology: the economy is a spontaneous order, subject to evolution in a non-deterministic way, as in biology.
Dominant theme	*Control:* economists can model and compute a complex system such as an economy.	*Cultivation:* economists are like farmers or gardeners.
Focus	Optimization of quantitative parameters	Institutions and agent interactions
Central planning	Feasible	Unfeasible
Government	Strong intervention to alter and replace the capitalist economic system.	A coevolutionary, polycentric, entangled, micro or even null role. Depending on the political characterization of government.

sible economies) to choose and implement planning. We argue that this conflicts with complexity theory, at least with its dynamic approach centered on the notion of *emergence*, which is the most widespread in economics. So at least here, cyber-communism is closer to the unrealistic neoclassical general equilibrium foundations of central planning than to complexity theory.

To hold a computational complexity view more focused on the algorithmic functioning of the economy and its optimization may be preventing cyber-communists from seeing the problems of central planning that the dynamic complexity perspective is able to identify. As we have analyzed in this section, some of these problems are self-reference, reflexivity, non-computability, and less adaptability. Consider, for instance, the adaptability problem. Our argument concludes that cyber-communism, if implemented, will potentially generate an economy with less adaptive capacity than a decentralized market system. A less adaptive capacity, in general, makes it more difficult for any system to become more complex, which in economics equals to prosper (Hausmann et al., 2013; Koppl et al., 2015), or even to survive if the economy gradually becomes less complex. Hence, we believe the obstacles and possible consequences of central planning just highlighted here are worth considering by cyber-communists if they aim to defend central planning over decentralized market planning as a preferable mode of organization.

4.2. Cyber-communism and complexity political economy

Being a computational complexity-based theory, we could expect cyber-communism to accord with the complexity political economy we outlined in section 3. However, as we are about to show, cyber-communist political economy reaches opposite conclusions to a complexity political economy.

Cyber-communism is based on computational complexity while advocating the control of the economy. Cockshott and Cottrell are explicit about the goal of controlling the economy throughout all their works. That is to say, the dominant theme in cyber-communism political economy is *control*, attributing a strong role to the government (Table 2). This may challenge the complexity political economy we previously presented, which energetically rejects *control* and supports *cultivation*. However, as we showed in the previous sub-section, cyber-communism faces fundamental problems in abstract terms even from a computational complexity view, e.g., self-reference. From this automatically follows that control is likewise ineffective, which disarticulates the core of the cyber-communist political economy. Nevertheless, there is still a risk that, from any complexity grounded perspective similar to cyber-communism, one can think that the economy can dispense with elementary institutions such as money or private property rights. Or even that one can effectively *cultivate* alternative types of institutions to those present ones, above mentioned. Due to this risk, we will elaborate here the fundamental problem of cyber-communism in light of a complexity political economy.

As it can already been inferred, the main issue with cyber-communism is its disregard for present, so-called, market institutions. It outlines a socialist system in which private ownership of the means of production and money are abolished, and the state becomes the owner of the means of production while labor certificates perform the role of money for consumer goods. The same happens to the figure of the entrepreneur, which Cottrell and Cockshott want to replace by a combination of expert opinion and democratic methods. They propose this alternative social organization assuming that their designed institutions will work even more efficiently than current market institutions.

The reason for this disregard for market institutions is their skepticism about the evolutionary view of the economy. Cottrell and Cockshott (1997a) criticize Hayek for marking superficial analogies and metaphors in economics from biology. They assert that, while there can be some parallelisms, evolution in biology and evolution in economics differ because the economy acts as a single processor, while this is not the case in biology due to the variety of species. Along the same lines, the authors then conclude that one cannot affirm that the capitalist system results from evolution. They make clear that evolution is not the same as history, and that capitalism is a historical result, not an evolutionary outcome. This is because an authentic evolutionary process, they contend, will require a considerable number of simultaneous economic systems to compete, and, in recent history, we only had two systems that competed for a short period of time, which is not a statistically valid sample.

Contrary to Cockshott and Cottrell, there is a vast literature on the economy as an evolutionary process, which precisely forms complexity economics. Many authors have shown the advantages of taking metaphors from biological processes rather than mechanical processes to address economic issues (Hodgson, 1995). One can apply the biological concept of diversity of species as diversity of products in economics to explain, for instance, the cause of wealth (Koppl et al., 2015). What is more, Beinhocker (2007) even believes that evolutionary laws are not genuinely biological, but are general laws of reality which can then be applied to concrete fields, to for instance, explain the evolution of species (biology) or the evolution of products and niches (economy). This evolutionary perspective has usually gone hand in hand with institutionalism. Both combined allow to understand how change takes place in the economy through the evolution of its institutions, conceived as transpersonal coordination mechanisms. These are two perspectives integrating complexity economics and have helped to overcome the restrictive and unrealistic assumptions of neoclassical economics and traditional political economy.

Cottrell and Cockshott only focus on the relatively recent dispute between the so-called capitalist and socialist systems, to ultimately assert that market or capitalist institutions such as private property rights or money are not really evolutionary. The use of concepts such as capitalism and socialism may be confusing, given that they receive a wide range of meanings. If we instead refer to market institutions versus socialist institutions, it may be easier to talk in evolutionary terms. For instance, let us consider private property versus communal property. History, as a parallel of evolution, has shown that societies operating with private property have become richer and more complex than groups with communal property. How many groups, tribes, and societies, since the emergence of civilizations, have worked under both types of institutions? Note that we are here covering all history of humankind, not only a short period of time. The outcome, regarding wealth, can be contrasted, and the cause lies in the predominant type of institution. Is not this process evolutionary?

Institutions such as money or private property rights, as defined in section 3, emerged through a long evolutionary process. As such, they all embody a great amount of factual and tacit knowledge, which means that these institutions have not been consciously created, but spontaneously emerged from the interaction of millions of individuals (Hayek, 1973). They allow transpersonal coordination in complex system notably populated, in the same way that language does (Horwitz, 1996). This explains why *cultivation* is the central theme of a complexity political economy and why it is an error to believe that institutions can be easily altered or replaced, ignoring the long evolutionary processes backing present market institutions. Consciously removing relevant institutions, as cyber-communism aims to do with private property of the means of production and money, can create harmful effects on incentives and coordination among agents, which can impair the emergent process and algorithmic working of the economy.

In a sense, the notion of *cultivation* implies a natural selection perspective, which holds that institutions should allow organically, without any external interference. Natural variation and selection mechanisms suffice to retain the fitter examples. However, artificial selection can contribute to and accelerate the natural selection process itself, and indeed, complexity theorists believe that the rules of the game can be changed and improved. Here, cyber-communists could argue that what they are trying is an artificial selection process to improve present institutions such as property rights or money. Still, evolutionary and complexity theories themselves point out that any variation should stay close to already existing, successful models or, in this case, institutions (Phelan, 2016). This means that the more contradictory the new institution is to existing successful institutions, the greater the probability that this new institution will fail or cause distortions in the system. Applied to the present discussion, insofar as cyber-communism aims to replace present successful market institutions (successful in the sense that they have allowed survival and reproduction in the system) such as private property rights and money with alternative or even opposite rules, it will generate distortions in the economic system. Can we be sure that this artificial selection of institutions will be detrimental to the economy?

Regarding property rights, there is a recent debate between Denis (2015), and Bylund and Manish (2017), contrasting public or *several* ownership of the means of production with private ownership of them. Denis (2015) upholds a decentralized economy, operating as the market does, but with public property in the means of production rather than private. He seems to try an artificial selection process; namely, copy the decentralized functioning of the market but with a different, improved institution. As Bylund and Manish (2017) show, despite Denis argues that the socialist economy he outlines would work in the same way as a market system, there are important differences in how managers of resources would make decisions in each system as a consequence of distinct incentive structures. In socialism, ownership is centralized in the government or the community, so agents using and investing capital are only managers, which means that they are not completely subject to the lure of profit and the risk of loss. In the market, there is a multitude of individual owners, who assume the risk of individual losses. The impact on individuals' property and not on the community indicates to us that managers in a socialist system will be more reckless and less cautious than in a market economy. Benefits can be concentrated, while costs dispersed throughout the community (Bylund and Manish, 2017). Thus, agency problems associated to the owner-manager relationship can intensify due to a different institutional frame, as with public property.

Bylund and Manish's conclusions serve to see how artificial selection, when not based on present, central rules, can alter incentive structures in a system and, in turn, agents' behavior and system's outcome. Specifically, with the institution of private property rights, which cyber-communism wants to remove. Furthermore, even in the case that cyber-communists or other advocates of the so-called *digital socialism* propose technology such as Machine Learning to replace existing institutions, Fernández-Villaverde (2021) argues that simple, evolutionary rules are much better in creating incentives to elicit information so that the economy can operate.

From this discussion, it has to be clear that any political economy claiming to be based on complexity theory should take present institutions as central, and then *cultivation* as the dominant theme from a natural selection perspective or, at least, proposing artificial selection close to existing institutions and models. Cyber-communism, despite based con computational complexity theories, opts for control as a dominant theme. It rejects the evolutionary analysis of market institutions and adopts an artificial selection view that aims to replace successful institutions central to the economy. Ultimately, this artificial selection perspective can alter the incentive structure of agents in the economy if implemented, intensifying agency problems, which will harm the economic process. Cyber-communism is then far from being a complexity political economy, and therefore resembles some ideas of traditional political economy such as the emphasis on control and the role of government.

5. Conclusion

The introduction of complexity theory into economics can result in paradigmatic shifts. For political economy, complexity entails a new vision different from traditional theory, emphasizing *cultivation* of institutions as the dominant metaphor, rather than *control* of economic parameters.

Complexity economics and its political economy shed light on the issue of cyber-communism, given that the latter is based on computational complexity theory. Complexity shows that central planning faces a self-reference problem leading to noncomputability. Also, that decentralized systems of decision making such as the market are superior to cyber-communist centralized planning according to an adaptability criterion. Cyber-communists seem to adopt a strictly computational approach, centered on optimization, which leads them to erroneously assume pregiven and knowable phase spaces of the economy and obviate that the economy, as another evolutionary process, is creative and emergent. It cannot be planned *ex ante*.

Cultivation, as the central concept for a complexity political economy, warns us that the economy is not a perfect mechanism that can be effectively manipulated without causing unintended consequences, drawing our attention to take care of existing successful institutions such as private property rights or money. In contrast, despite sharing a computational complexity view of the economy, cyber-communism advocates control of the economy. It denies that market institutions result from a genuine evolutionary process and relies on artificial selection by proposing to replace the rules of the game. We have shown that evolutionary laws equally apply to the economy, that market institutions are evolutionary, and that cultivation should mainly embrace a natural selection perspective rather than an artificial one. Variation should stay close to already successful rules and institutions, and cyber-communism contradicts this idea. Therefore, cyber-communism appears closer to the traditional political economy of control than to a complexity political economy of cultivation. Complexity science, as a new movement, helps scholars to understand the world better than previous theories. It allows us to identify limits and realistic possibilities of science. Being closer to traditional paradigms than to complexity, cyber-comunism fails to understand the limitations and realism of its model.

This work also responds to a more general question: can advances in computer technology ease central planning? As shown, effective central planning is not feasible in light of complexity theory, not due to a technological or practical issue, but due to ontic and epistemic reasons related to the nature of complex systems. In this sense, this article may prompt those who seek control or model the economy through technology from alternative perspectives to cyber-communism to consider the noncomputability of optimal parameters and the emergent dynamics of the economy, which cannot be fully anticipated. Additionally, the complexity political economy outlined here, emphasizing the notion of *cultivation*, can be used in future works on political economy aiming to consistently follow the principles of complexity economics.

Declaration of Interest

The authors declare that there are no conflicts of interest.

Data Availability

No data was used for the research described in the article.

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