MECHANISMS AND SCIENTIFIC METHODOLOGY: STRENGTHS AND WEAKNESSES OF THE NEW MECHANICAL PHILOSOPHY

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Contents

Summary

1. Mechanisms in science

Mechanisms are frequently invoked in the scientific literature. Hundreds of papers that refer to mechanisms are published every year in journals such as *Nature*, *Science*, and *The Lancet*. The mechanism-talk spreads across the whole range of science; it is not confined to certain particular areas. Scientists discuss "regulation mechanisms", "mechanisms of action", "allocation mechanisms", "selection mechanisms", "mechanisms of suppression", etc. in very diverse fields. It certainly seems that mechanisms play an important part in the scientific enterprise. Nonetheless, that is not entirely surprising. The main aims of science are to describe, explain, predict, and control worldly phenomena. And mechanisms are relevant in order to achieve those goals. They reveal *how* the phenomena of the world—i.e., the subject of scientific investigation—are constituted or produced.

In order to illustrate the relevance of mechanisms, consider inequality of success in cultural markets. Successful cultural products (e.g. best-selling books) are orders of magnitude more successful than average. More than one hundred million copies of *Harry Potter and the Philosopher's Stone*—the first book of the Harry Potter series—have been sold since its publication in 1997, while most authors only manage to sell a few hundred copies of their cherished manuscripts. Likewise, *Avatar* grossed 749 million dollars at the domestic box office; more than forty-six times the average USA box office in 2010. The commonsense explanation of that inequality appeals to intrinsic attributes of successful products (e.g. narrative structure) (Watts, 2011). We are inclined to considered that those products are qualitatively different from their peers and that that difference is responsible for their overwhelming success. However, that explanation is undermined by the unpredictability of cultural markets. Even experts are usually unable to determine in advance which products will make it to the top. In fact, *Harry Potter and the Philosopher's Stone* was rejected by twelve publishers before being accepted for publication (Gunelius, 2008).

Then, in order to adequately account for inequality of success in cultural markets, it is crucial to identify the mechanism that is responsible for it. The sociologists Salganik, Dodds, and Watts (Salganik et al., 2006; Salganik & Watts, 2009a, 2009b) have addressed how the (non-independent) behaviour of individual consumers leads to inequality of success. Social influence is present in cultural markets, where information about the success of offered products is often available (e.g. best sellers lists). Due to the huge amount of offered cultural products, individuals are likely to follow others' choices and buy those products that are already popular. This tendency is also reinforced by structural features of many cultural markets, such as giving best-selling books a more prominent in-store placement. Therefore, cumulative advantage operates. Cultural products that are successful tend to become still more successful. Initially small differences become large differences and, consequently, inequality increases. In Salganik, Dodds, and Watts' work, the presence of social influence in cultural markets and its contribution to inequality of success are supported by experimental studies in artificial cultural markets (see Salganik et al., 2006; Salganik & Watts, 2009b).

The central role of mechanisms is also manifest in the practice of the International Agency for Research on Cancer (IARC). The objective of IARC is to prepare and publish scientific reviews and evaluations of evidence on the carcinogenicity of particular agents (e.g. environmental exposures) (IARC, 2019). On the basis of the available evidence, it aims to stablish to what extent those agents can be considered carcinogenic to humans. Evaluation of agents is informed by three kinds of evidence: evidence of cancer in humans, evidence of cancer in experimental animals, and evidence of mechanisms. In that context, evidence of mechanisms mainly refers to information about toxicokinetics (e.g. metabolization) and processes of carcinogenesis (e.g. induction of epigenetic alterations). After separately analysing every individual study and assessing each stream of evidence in conjunction, the three kinds of evidence are integrated in an overall evaluation of the carcinogenicity of the agent. Then, according to that assessment, the agent is classified as carcinogenic to humans, probably carcinogenic to humans, possibly carcinogenic to humans, or non-classifiable as to its carcinogenicity to humans.

In the overall evaluation of agents, the main role of evidence of mechanisms is to guide the extrapolation of causal claims from animal models to humans (Leuridan & Weber, 2011). When evidence of cancer in humans is limited or inadequate, evidence of mechanisms is required in order to determine if the agent is carcinogenic to humans. That role of evidence of mechanisms was crucial in the evaluation of benzo[a]pyrene (IARC, 2012), which has been discussed in detail by Wilde and Parkkinen (2019). Although no evidence of cancer in humans (e.g. epidemiological data) was available, benzo[a]pyrene was classified as carcinogenic to humans. The identified similarity between the mechanisms operating in experimental animals and those operating in humans enabled the extrapolation of the causal claim. It was considered that "[t]he strong and extensive experimental evidence for the carcinogenicity of benzo[a]pyrene in many animal species, supported by the consistent and coherent mechanistic evidence from experimental and human studies provide biological plausibility to support the overall classification of benzo[a]pyrene as a human carcinogen" (IARC, 2012, p. 138).

Nevertheless, it should be noted that scientific practice sometimes fails to pay enough attention to mechanisms. An example of this neglect is the thalidomide disaster (Brynner & Stephens, 2001). In contrast to the evaluation of benzo[a]pyrene, in that case evidence of mechanisms was not taken into account. In the 1950s, because of the Cold War and the psychological sequelae of World War II, anxiety and insomnia were quite widespread in Europe and USA. Tranquilisers and sleeping pills became everyday products. However, most of the sedatives were dangerous barbiturates and a safer alternative was demanded. In that scenario, Chemie Grünenthal, a German pharmaceutical company, accidentally produced thalidomide. After testing it in animal trials and not observing side effects—no dose was high enough to kill experimental animals—the Grünenthal team looked for a disease that thalidomide could cure. They soon found that thalidomide had a calming and sleep-inducing effect on patients without decreasing motor activity. In October 1957, thalidomide was released as a sedative in Germany and, in a few months, it was available in almost fifty countries around the world. It was advertised as a completely safe sedative, which was appropriate for children and pregnant women. However, thalidomide may produce birth defects (e.g. phocomelia) when it is taken by pregnant women. In November 1961, after it was linked to birth defects by several reports, thalidomide was withdrawn from the market in Germany. And over the next months, it was withdrawn in the remaining countries. Nevertheless, it has been estimated that 8.000 to 12.000 infants were deformed by thalidomide during its marketing period.

As Donald Gillies (2017) has argued, it is unlikely to be the case that randomized control trials (RCTs) conducted in humans or more animal trials would have reveal thalidomide's potential to cause birth defects if taken by pregnant women. On the one hand, pregnant women cannot take part in RCTs and, on the other hand, thalidomide hardly produces birth defects in animals other than primates. Nonetheless, considering evidence of mechanisms would have revealed the teratogenic potential of thalidomide and helped to avoid the disaster (Gillies, 2017). Firstly, analysing thalidomide's mechanism of absorption would have showed that, given its molecular weight, thalidomide could cross the placenta and enter the foetus. And secondly, comparing the mechanisms operating in animal models and the mechanisms operating in humans would have revealed relevant differences between them and undermined the safety claim.

In summary, mechanisms have a central role in the scientific enterprise. As the above examples evidence, mechanisms are often crucial for achieving goals such as explanation and reliability in causal inference. The lack of knowledge about mechanisms may severely hamper scientists' labour. Consequently, an accurate discussion of scientific methodology cannot overlook mechanisms and their important contributions.

2. Mechanical philosophies

The relevance of mechanisms and mechanism-based approaches has not gone unnoticed for philosophers. In fact, the first 'mechanical philosophy' dates back to the Classical Greece (c. 500–c. 323 BCE) (Popa, 2018).[1] Democritus of Abdera argued that the world is composed of two different kinds of realities: atoms and void. Atoms are invisible, ingenerated, unchangeable, and indestructible. They are homogenous and only differ in their shape and size. On the other hand, void is characterised as absolute non-being. Atoms, which are infinite in number, move in the infinite void and combine into different clusters. Macroscopic objects are actually clusters of invisible atoms and their properties depend on which atoms constitute them. Changes in those objects are the result of rearrangements of atoms. In Democritus' atomism, it is considered that every worldly phenomenon is explicable in terms of atoms, their properties, and their interactions (Hankinson, 1998; Popa, 2018). In the Hellenistic period (c. 323–c. 30 BCE), the atomist theory was adopted and developed by the Epicureans. They addressed psychological aspects like will and desire and offered mechanistic explanations of them in terms of interactions between atoms. Furthermore, Epicureans vindicated "the value of atomist theory for teaching us how to live the untroubled and tranquil life" (Berryman, 2016).

In ancient natural philosophy, the atomists' mechanical approach was criticised by advocates of teleological explanations. Those authors consider that natural phenomena should be explained by reference to functions, goals, or ends. Nevertheless, artefactual or technological analogies are occasionally used by them as explanatory resources (Berryman, 2003). For example, Aristotle compares the movement of animals to automatic mechanical devices. In animals, like in automata, an initial impetus leads to

[1] Berryman (2003) argues that there was no real mechanical approach until the Hellenistic period. She defines a mechanical approach as "a method of investigating the natural world through terms and principles drawn from the discipline called 'mechanics'" (Berryman, 2003, p. 344). And according to that characterisation, mechanical conceptions were not possible before the development of mechanics, which took place during the fourth century BCE. Nevertheless, Berryman's idea of mechanical approach is too narrow and does not suit contemporary understanding of mechanisms.

movement. Moreover, after that initial impetus, both of them can continue moving in virtue of their internal organisation.

In the second half of the seventeenth century, the experimentally practiced mechanical philosophy became the dominant approach in natural philosophy. It was influenced by the contemporary mechanical arts and mathematical sciences, and opposed to Aristotelian science and vitalism. The modern mechanical philosophy as a general program was introduced by Robert Boyle (Roux, 2018).[2] It involves a reductionist worldview according to which passive matter and motion are the ultimate constituents of the world. There is only one universal matter, which is extended, divisible, and impenetrable. Motion, which is always local, divides matter in parts of various sizes and shapes. The variety of worldly phenomena results from the different shapes, sizes, motions, and relations of parts of matter. Apart from a metaphysical position, the modern mechanical philosophy is a thesis about scientific methodology (Nadler, 1998; Psillos & Ioannidis, 2019). It argues that phenomena must be explained in terms of matter and motion. In a satisfactory explanation, the explanans specifies how certain configuration of matter in motion, subject to laws, brings about the phenomenon of interest.

The seventeenth-century mechanical philosophy, unlike Aristotelian natural philosophy and vitalism, rejects a sharp distinction between artificial and natural beings (Garber, 2002; Hattab, 2011). It is considered that, although they differ in their cause, their nature is very similar. Natural beings are simply more complex machines. There is no fundamental difference between the behaviour of natural and artificial phenomena. And, consequently, both must be explained in terms of matter and motion. In this sense, for instance, mechanistic explanations of the self-movement of living things are developed (Des Chene, 2005). Furthermore, artificial devices (e.g. animated apes) are often used for explaining natural phenomena. The mechanisms governing natural phenomena are rarely visible, but the inner mechanisms of artificial devices are usually larger. So artificial devices enable mechanical philosophers to illustrate those invisible mechanisms. As de Solla Price argues, their "very existence offered a tangible proof,

[2] Boyle introduced the general program of the mechanical philosophy in the preface of *Some specimens of an attempt to make chymical experiments useful to illustrate the notions of the corpuscular philosophy* published in his *Certain Physiological Essays* (1661). The term 'mechanical philosophy' had been previously used to characterise Descartes' philosophy (Roux, 2004). For example, in a letter sent to Descartes in 1637, Libert Froidmont claimed that his philosophy was too gross and mechanical because of its influence of Epicurean physics. However, as Roux (2018) has argued, those occurrences of the term should not be equated to the establishment of the mechanical philosophy as a general program. They did not provide a framework within which different accounts are possible; they exclusively denoted Cartesian philosophy.

more impressive than any theory, that the natural universe of physics and biology was susceptible to mechanistic explanation" (1964, p. 9).

Boyle provided a general and broad characterisation of mechanical philosophy. Within the mechanical framework, distinct accounts are allowed (Boas, 1952; Psillos, 2011). Mechanists can have different ideas about the structure of matter, the primary properties of matter, the reality of void, etc. Descartes is usually depicted as a paradigmatic example of mechanist (Roux, 2004). Descartes holds that matter, which is infinitely divisible, and motion are the fundamental constituents of the world. He considers that laws of motion are able to explain every worldly phenomenon. In this sense, he claims that physics is nothing else than mechanics—i.e., the study of motion. Furthermore, his explanations often refer to artificial devices (e.g. automata). Nevertheless, other philosophers such as Thomas Hobbes, Pierre Gassendi, or John Locke, who disagree in many aspects with the Cartesian approach, would also be considered mechanists. In fact, soon the notion of mechanical philosophy was extended to include all those who advocated the relevance of mechanistic explanations, regardless of whether they endorsed the mechanical ontology (Roux, 2018). In this sense, most of the key figures of science and philosophy of the seventeenth century, such as Isaac Newton and Gottfried Wilhelm Leibniz, can be characterised as mechanists.

Modern mechanical philosophers acknowledged the influence of ancient atomism (Buyse, 2013). The seventeenth-century mechanical philosophy is also a reductionist worldview in which homogeneous matter is considered one of the main constituents of the world. Moreover, it holds that phenomena must be explained in terms of matter, motion, position, and other mechanical qualities of bodies. Nevertheless, there are relevant differences between ancient atomism and modern mechanical philosophy (Bennett, 1986). On the one hand, many mechanists reject central thesis of atomism. For example, Descartes considers that there is no void and that matter is infinitely divisible. And on the other hand, the modern approach includes many aspects absent in ancient philosophy, such as the experimental method, the use of mathematical instruments, and the development of mechanistic models.

In the following centuries, the mechanical approach remained as the main trend in the sciences. Scientific research was often related with the development of mechanical models that accounted for observable phenomena. Representative examples of those models are the kinetic model of gases (James Clerk Maxwell) and the hexagonal model of the benzene molecule (August Kekulé). Nonetheless, there was no standard interpretation of the mechanical philosophy shared by all the scientists. The interpretation could vary depending on the period, the region, and even the institution (Smith, 1976; Baracca, 2005). The plurality of mechanical approaches ranged from those that advocated explanations in terms of interactions between non-observable elementary entities to those that focused on developing systems of laws on the basis of the fundamental principles of dynamics.

In spite of its prevalence, the mechanical approach was subject of criticism. This criticism was especially fierce in biology (Allen, 2005, 2018). Several authors claimed that the mechanical philosophy was an over-simplistic way of viewing living organisms and raised alternative proposals. Those alternative accounts were usually based on the idea that living organisms show emergent properties and must be studied as unified wholes. It was considered that they cannot be reduced to its components. In the 1700-1850 period, most philosophers and scientists critical of the mechanical approach, such as Xavier Bichat and Johannes Peter Müller, advocated some form of *vitalism*. They held that some immaterial force, which have no counterpart in the non-living world, characterises living organisms. Nevertheless, in the latter nineteenth and early twentieth centuries, several materialistic alternatives to the mechanical approach were also advocated (e.g. dialectical materialism). Holistic materialists considered that, in order to understand complex systems, it is necessary to get beyond the individual parts and address them as wholes. But they rejected any forces that could not be understood in terms of the known physics and chemistry. Holistic materialists aimed to account for complex systems in purely physico-chemical terms.

For most of the twentieth century, the philosophy of science was dominated by the *logical empiricism* and the covering-law model of scientific explanation. According to this model, a phenomenon is explained by subsuming it under a law (Hempel, 1965). Explanations are characterised as arguments where the premises, which contain essentially at least one law, imply (with deductive certainty or high inductive probability) the conclusion, which describes the explanandum phenomenon. However, from the early 1960s, many counterexamples that show that subsumption under laws is unnecessary and insufficient for exampling scientific phenomena were raised (see Salmon, 1989). In that context, some philosophers such as Peter Railton and Wesley C. Salmon developed mechanical accounts as alternatives to the eroded covering-law model.

Railton (1978) criticised the covering-law account of probabilistic explanations of particular phenomena—i.e., the inductive-statistical model. According to that model, a probabilistic explanation is an argument in which the premises, which include essentially at least one statistical law, imply with high inductive probability the conclusion, which describes the explanandum phenomenon. Railton disputes that probabilistic explanations are arguments and that they must render the explanandum highly probable. He considers that we understand improbable phenomena just as well as we understand highly probable phenomena. Railton argues that probabilistic explanation is not about making the explanandum phenomena nomically expectable, but about understanding the stochastic mechanisms by which they came to occur. Consequently, he claims that a probabilistic explanation of a phenomenon must "give an account of the chance mechanism(s) responsible for it" (Railton, 1978, p. 206). He understands a mechanism as "a more or less complete filling-in of the links in the causal chains" (Railton, 1978, pp. 208-209).

In his influential *Scientific Explanation and the Causal Structure of the World* (1984), Salmon argues that "[t]o understand the world and what goes on in it, we must expose its inner workings. To the extent that causal mechanisms operate, they explain how the world works" (1984, p. 133). He considers that explaining a phenomenon is to show how it fits into the causal structure of the world. A phenomenon is satisfactorily explained when (some portion of) the causal processes and interactions leading up to it are specified. Salmon characterises causal processes and causal interactions in terms of the counterfactual criterion of 'mark transmission'. A causal process is defined as a process capable of transmitting a mark (i.e. a modification in its structure), whether or not it is actually transmitting one (Salmon, 1984, p. 147). A paradigmatic example of causal process is the movement of a free particle. Causal interactions are intersections of two causal processes in which both are persistently modified in a way that would not have occurred without the intersection (Salmon, 1984, p. 171). A collision of two particles, for instance, would constitute a causal interaction. Nevertheless, it was argued that those definitions of causal process and causal interaction admit counterexamples and are not reliable guides to the discovery of the causal structure of the world (Kitcher, 1989; Dowe, 1992). In response to those critiques, following Phil Dowe (1992), Salmon redefined those concepts in terms of conserved quantities. A causal process is characterised as "a world-line of an object that transmits a nonzero amount of an invariant quantity at each moment of its history (each spacetime point of its trajectory)" (Salmon, 1994, p. 308). A causal interaction occurs when world-lines intersect and a conserved quantity is exchanged (Salmon, 1994, p. 303).

Salmon's proposal, like the seventeenth-century mechanical philosophy, is ontologically austere (Hitchcock, 1995). The causal structure of the world is reduced to physical processes and interactions. Nonetheless, Salmon considers that the causal mechanical model can account for most explanations in science. In this sense, he says: "I hope that the causal theory of scientific explanation outlined above in this book is reasonably adequate for the characterization of explanation in most scientific contexts—in the physical, biological and social sciences—as long as we do not become involved in quantum mechanics" (Salmon, 1984, p. 278). Certainly, it suits most simple physical systems, whose behaviour is governed by the principles of classical mechanics and electromagnetism. However, as James Woodward (1989) early noted, Salmon's proposal can hardly account for explanations in fields such as biology, psychology, and economics. In those fields, systems that significantly differ in their underlying physical structure are often treated as similar. For example, consider adaptative situations. When the present selective pressures are analogous, two adaptative situations may be considered similar even though the actual mechanisms underlying them are quite different. This idea is at the basis of the models developed in evolutionary game theory.

3. The new mechanical philosophy

The *new mechanical philosophy* emerged between the late 1980s and the early 1990s. This emergence was related to the publication of books such as *Nuts and Bolts for Social Sciences* (1989) by Jon Elster and *Discovering Complexity: Decomposition and Localization as Strategies in Scientific Research* (1993) by William Bechtel and Robert Richardson. The new mechanical approach opposes to logical empiricism and the 'laws-and-theories' image of science. It is considered that scientific inquiry should not be understood as a search for universal laws, but as a search for mechanisms. Those mechanisms are represented by mechanistic models, which play the role of theories. Scientists use mechanistic models for representing, explaining, predicting, and intervening in the world.

Within the new mechanical philosophy, two strands can be distinguished: the 'new mechanism' and the 'social scientific mechanism' (Glennan & Illari, 2018). The new mechanism, which engages with Bechtel and Richardson's seminal work, has been mainly developed by philosophers of science working in the life sciences (biology, neuroscience, medicine, etc.). Some crucial early contributions, which partially defined it, are "Mechanisms and the Nature of Causation" (1996) by Stuart Glennan and

"Thinking about Mechanisms" (2000) by Peter Machamer, Lindley Darden, and Carl F. Craver (henceforth MDC). Those papers characterise mechanisms and, taking them as reference, address several philosophical problems such as causation and scientific explanation. The social scientific mechanism, which engages with Elster's influential work, focuses on the social sciences, especially on sociology and economics. It has been developed by social scientists and is intimately related with analytical sociology. Analytical sociology is a methodological movement within sociology that underlines the relevance of mechanisms. Its fundamental principles have been exposed in books such as *Social Mechanisms: An Analytical Approach to Social Theory* (1998) edited by Peter Hedström and Richard Swedberg and *Dissecting the Social: On the Principles of Analytical Sociology* (2005) by Hedström. One of its core ideas, which is shared by all analytical sociologists, is that the main aim of sociology should be to explain social macro-phenomena by means of the mechanisms that are responsible for them.

The new mechanism and the social scientific mechanism arose independently and, for some years, the discussions within philosophy of science and social sciences proceeded separately. Nonetheless, the interaction between both strands has progressively grown. For example, notions of mechanism developed by advocates of the new mechanism have been adopted by social scientists involved in the social scientific mechanism (see, for instance, Hedström, 2005, p. 25).

Like previous mechanical approaches, such as modern mechanical philosophy and Salmon's proposal, the new mechanical philosophy is both a philosophy of nature and a philosophy of science (Glennan, 2016, 2017). On the one hand, it is a philosophical inquiry into the constitution and organisation of the world. New mechanists consider that mechanisms are one of the main constituents of the world and that most or all worldly phenomena depend on them. They investigate the nature of mechanisms as an ontological category and how they relate with other ontological categories such as causes, properties, and levels of organisation. On the other hand, the new mechanical philosophy is a philosophical inquiry into science. It is considered that mechanisms have a central role in the scientific enterprise. New mechanists discuss the discovery of mechanisms, their representation by means of models, and their use to explain, predict, and control phenomena. It should be noted that not all mechanists attach the same importance to those projects and are equally involved in them. In fact, some of them focus on one project and almost ignore the other. For example, consider Gillies (2017, 2018), to whom I have referred in section 1. He carefully analyses how evidence of mechanisms can contribute to causal inference and causal extrapolation, but he devotes little attention to mechanisms as an ontological category.

Nevertheless, unlike previous mechanical approaches, the new mechanical philosophy is characterised by a general emphasis on actual scientific practice (Machamer et al., 2000; Glennan, 2017; Psillos & Ioannidis, 2019). The new mechanists' primary object of interest is mechanism as a concept-in-use in science, not as an abstract metaphysical category. They are concerned about what mechanisms are and what they are (or could be) good for in the sciences. The new mechanists focus on scientific practice and take it as the main reference for addressing both methodological and ontological questions related with mechanisms. It is considered that ontological claims about mechanisms as constituents of the world cannot overlook the role of mechanisms in science and scientists' considerations about them (Kaiser, 2018). For example, the discussion about what kinds of components make mechanisms up and what is the relation between them—i.e., is one kind more fundamental than the others or are they ontologically on a par?—is guided by the criterion of descriptive adequacy (see, for instance, Machamer et al., 2000). According to it, a satisfactory proposal must suit paradigmatic examples of mechanisms studied by scientists.

The new mechanical philosophy, as the seventeenth-century mechanical philosophy, is not a completely homogeneous movement. New mechanists do not have identical views and interests. Instead, the new mechanical philosophy is a framework within which distinct proposals, which may even conflict with each other, are advocated. In fact, although all new mechanists agree on the relevance of mechanisms, they disagree regarding the definition of mechanism. Within the new mechanical framework, there have been several attempts to offer a satisfactory characterisation of mechanisms (Mahoney, 2001; Hedström & Ylikoski, 2010). These are the most cited definitions:

> Mechanisms are entities and activities organized such that they are productive of regular changes from start or set-up to finish or termination conditions. (Machamer et al., 2000, p. 3)
>
> A mechanism for a behavior is a complex system that produces that behavior by the interaction of a number of parts, where the interaction between parts can be characterized by direct, invariant, change-relating generalizations. (Glennan, 2002, p. S344)
>
> A mechanism is a structure performing a function in virtue of its component parts, component operations, and their organization. The orchestrated functioning of the

mechanism is responsible for one or more phenomena. (Bechtel & Abrahamsen, 2005, p. 423)

A mechanism for a phenomenon consists of entities and activities organized in such a way that they are responsible for the phenomenon. (Illari & Williamson, 2012, p. 120)

Nonetheless, despite the disagreements among new mechanists, some general ideas are shared by most of them. First, mechanisms are part of the real world (Glennan, 2016, 2017; Glennan & Illari, 2018). They are conceived as particular things that are located somewhere in space and time. New mechanists always discriminate between a mechanism, which is a real thing, and a model of it, which is often a piece of scientific reasoning. Although there are discrepancies regarding the stability attributed to mechanisms. Some new mechanists consider that all mechanisms are complex systems, i.e., stable configurations of several components (e.g. Bechtel & Abrahamsen, 2005). But others argue that causal processes, which are less stable and cannot be considered objects, can also constitute mechanisms (e.g. Illari & Williamson, 2012). Second, mechanisms are composed of organised entities (or parts) and activities (or interactions) (Machamer et al., 2000; Illari & Williamson, 2012; Glennan, 2017). Entities are things that engage in activities. They are usually spatiotemporal located, structured, and oriented. Examples of entities are neurons, firms, and organs. Activities are productive happenings. They have temporal order, rate, and duration. Examples of activities are transporting, radiating, and buying. Entities and activities within a mechanism are organised. That organisation can have many different aspects, such as temporal, spatial, causal, etc. Third, a mechanism is always a mechanism for some phenomenon (Glennan, 1996, 2017; Hedström & Ylikoski, 2010). For instance, a digestive system is a mechanism that underlies the phenomenon of digestion. The identification and delimitation (i.e. the fixation of boundaries) of a mechanism depend on the phenomenon for which it is responsible. A mechanism cannot even be identified without saying what it is that the mechanism does. And fourth, there are significative differences between mechanisms and machines (Glennan, 2017; Craver & Tabery, 2019). Although human-made machines (e.g. watches) can often be considered mechanisms, most mechanisms studied in science are not machines. Their behaviour cannot be reduced to some fundamental mechanical forces. Nevertheless, the machine metaphor is still considered a helpful tool for illustrating the behaviour of complex natural systems.

Another core idea shared by all new mechanists is that mechanisms are nested and form a hierarchy (Machamer et al., 2000; Glennan, 2017). Mechanisms can be broken into lower level mechanisms. A mechanism is composed of organised entities and activities, which are responsible for its properties and behaviour. And those components are usually mechanisms themselves, whose properties and behaviour also depend on their own components. For instance, components of a nervous system (brain, spinal cord, nerves, signal transmission, etc.), which are responsible for its properties and behaviour, are themselves mechanisms. Nonetheless, unlike previous mechanists, the new mechanists do not advocate a reductionist worldview (Andersen, 2014). They reject that it is possible to reduce higher level mechanisms to lower level mechanisms. Although there are ontological and explanatory relations between higher and lower levels, it does not lead to the elimination of the higher levels nor to the reduction of them to the lower ones. The new mechanists take seriously the reality of complex things. They hold that new and different kinds of entities and activities arise at different levels of organisation. Furthermore, the new mechanists consider that higher level explanations can be perfectly legitimate (Machamer et al., 2000), so that scientific explanations do not have to be grounded in some predetermined fundamental level (e.g. fundamental physics). What counts as proper bottom-out components is domain-dependent and methodologically motivated.

In spite of its novelty and originality, the new mechanical philosophy engages in the mechanical tradition from which it inherits some of its central ideas. In this sense, several important aspects of the new mechanical philosophy were anticipated by Salmon (1984, 1994, 1998). In fact, regarding the relationship between Salmon and contemporary mechanists, Campaner has claimed that "his work already presents many interesting hints at what are now regarded as the crucial steps *forward* in dealing with mechanistic causation" (2013, p. 82). Salmon already stresses the notions of production and interaction, which have a central role in the new mechanical approach. New mechanists underline the active nature of mechanisms (Machamer, 2004; Glennan, 2017). They account for mechanisms as entities engaged in productive activities or interactions. Furthermore, in both cases, productive *continuity* is crucial. As we have seen, Salmon (1984, 1994) claims that spatio-temporal continuity characterises causal processes and distinguishes it from pseudoprocesses. New mechanists consider that productive continuity between stages makes their relations intelligible and is responsible for mechanisms' regularity (Machamer et al., 2000). Another aspect of the new mechanical philosophy that is already present in Salmon's proposal is the central role of active or experimental counterfactuals. In the original version of the causal mechanical model, Salmon (1984) appeals to experimental counterfactuals to distinguish genuine causal processes and interactions from non-causal ones. And in the new mechanical philosophy, interventionist counterfactuals are considered crucial in order to identify relevant variables and determine mechanisms' components (Glennan, 2002; Craver, 2007).

Regarding scientific explanation, Salmon (1984) also introduces many ideas subsequently advocated by the new mechanical philosophy.[3] He claims that, in order to develop an accurate account of scientific explanation, scientific practice itself must be considered and that explanations in most scientific fields are indeed mechanistic. Salmon (1984, p. 175) also underlines the etiological and constitutive aspects of mechanism-based explanations. In order to explain why a given event E occurred, the relevant causal processes and interactions belonging to E's past must be identified. Nevertheless, if one wants to explain why E possesses certain characteristics, they have to reveal the internal causal mechanisms that account for E's nature. Another aspect anticipated by Salmon is acknowledging the relevance of function and context in a mechanical approach. He (1998) argues that functional explanations are legitimate and constitute a subset of mechanistic explanations. New mechanists, with respect to functional analysis, claim that it can be crucial for delimiting mechanisms and elaborating explanative mechanistic models (Bechtel & Abrahamsen, 2005). Regarding context, Salmon (1984, 1989) considers that it has a central role in the analysis of mechanisms. He argues that, although there is a thoroughly objective causal structure underlying phenomena, the aspects of the causal structure we select and the level of description we choose depend on the context. Similarly, new mechanists claim that the appropriate level of 'graininess' in mechanistic models is context-dependent (Craver, 2001; Bogen, 2005).

Nevertheless, it should be noted that there are significative differences between Salmon's causal mechanical model and the new mechanical philosophy. Although Salmon is also concerned about the role of mechanisms in science, his initial object of interest are metaphysical categories (Psillos & Ioannidis, 2019). Unlike the new mechanical approach, he starts discussing causal processes and interactions as abstract metaphysical categories. And subsequently, taking that analysis as the reference frame, he addresses methodological questions. Both mechanical approaches also differ in those

[3] The new mechanical account of scientific explanation and the central role of those ideas will be discussed in section 4.

scientific fields that are seen as inspiring. Salmon's approach is focused on physics, particularly, on a subfield of it: classical mechanics. However, new mechanists consider several fields such as biology, neuroscience, and sociology. There are also important differences regarding the notion of mechanism itself (Glennan, 2002). Firstly, while contemporary mechanists carefully discuss the characterisation of mechanisms and their current role in science, Salmon pays little attention to those issues. He does not provide an explicit definition of mechanism, nor take into account the diverse roles they play in science. Secondly, in Salmon's proposal, it is considered that all mechanisms consist of sequences of causal processes and interactions (e.g. a sequence of collisions among particles). However, new mechanists hold that mechanisms can be stable configurations of entities and activities (e.g. a cell).[4] Finally, although causal interactions are important in both accounts of mechanisms, they are understood in different ways. In the new mechanical approach, interactions are often characterised in terms of invariant change-relating generalisations (Woodward, 2003).

4. The new mechanical account of scientific explanation

According to the new mechanical philosophy, the role of mechanisms in science is often associated with the scientific objective of explaining. As previous mechanists, new mechanists advocate a mechanical account of scientific explanation. They consider that a phenomenon is explained by means of specifying the mechanism that is responsible for it. In this sense, MDC say: "To give a description of a mechanism for a phenomenon is to explain that phenomenon" (Machamer et al., 2000, p. 3). The mechanical approach opposes to covering-law and statistical accounts of scientific explanation (Bechtel & Abrahamsen, 2005; Hedström, 2005). Covering-law and statistical explanations are 'black-box explanations'. They connect initial conditions with final output by means of universal laws or statistical generalisations. However, the processes through which explanans and explanandum are actually linked are not addressed by them. It is considered that the link between explanans and explanandum is devoid of structure or that its structure is irrelevant. On the contrary, mechanistic explanations are how-explanations. They specify "how some phenomenon comes about" (Glennan, 2017, p. 228). Therefore, mechanistic explanations open the black box between explanans and

[4] Although some new mechanists agree that certain causal processes can be considered mechanisms, they do not claim that all mechanisms are causal processes. As it has been noted, those authors acknowledge that many mechanisms are stable complex systems.

explanandum and detail the processes that give rise to the later. A paradigmatic example of mechanism-based explanation is Salganik, Dodds, and Watts' explanation of inequality of success in cultural markets (see section 1). The authors specify the social cogs and wheels of the causal process through which that social macro-phenomenon is produced. They detail how the (non-independent) behaviour of individual consumers brings about that successful cultural products are orders of magnitude more successful than average.

Regarding the relation between mechanisms and phenomena of interest, mechanism-based explanations can be causal or constitutive (Ylikoski, 2013). Both causation and constitution are relations of dependence, but there are relevant metaphysical differences between them. Causation is often a relation between events, takes time, and is asymmetric regarding manipulation (i.e. a change in the effect can be produced by manipulating the cause, but not the other way around). On the other hand, constitution is often a relation between properties, is synchronic, and is symmetric regarding manipulation (i.e. a change in the whole can be produced by manipulating a part of it, and vice versa). Depending on the relation between the identified mechanism and the phenomenon of interest, an explanation is either a causal mechanistic explanation or a constitutive mechanistic explanation.

Among the new mechanists, there is no consensus about the nature of mechanistic explanations (Illari, 2013). Following Salmon (1984), some new mechanists consider that mechanistic explanations are *ontic* explanations. They argue that mechanism-based explanations explain because they fit the explanandum phenomenon into the causal structure of the world. For those authors, explanations are objective portions of the causal structure of the world. In this sense, Craver says: "Objective explanations are not texts; they are full-bodied things" (2007, p. 27). Nonetheless, other new mechanists consider that mechanism-based explanations are *epistemic* explanations. They hold that "[e]xplanation is fundamentally an epistemics activity" (Bechtel, 2008) and that mechanism-based explanations explain because they increase our understanding of the world. For advocates of the epistemic view, mechanistic explanations are not portions of the causal structure of the world, but representations of those portions (e.g. texts).

Mechanistic explanations are often presented by means of mechanistic models. A mechanistic model has two components: a phenomenal description and a mechanistic description (Glennan, 2017). The phenomenal description is a model of the phenomenon of interest, while the mechanistic description is a model of the mechanism responsible for that phenomenon. In mechanism-based explanations, the phenomenal description is related with the explanandum and the mechanistic description is related with the explanans. Nevertheless, there is no agreement about the details of those relations. From the ontic conception of mechanistic explanations, the phenomenal description would *represent* the explanandum and the mechanistic description would *represent* the explanans. However, from the epistemic conception, the phenomenal and the mechanistic descriptions would themselves *be* the explanandum and the explanans respectively.

5. The aim of generality and the heterogeneity of scientific fields

A central aspect of the new mechanical philosophy that has not been previously discussed and deserves attention is the *aim of generality*. New mechanists consider that mechanisms are relevant in most scientific fields and attempt to provide a general mechanical approach that encompasses all of them. The pursuit of generality and broad applicability is manifested in most proposals developed within the framework of the new mechanical philosophy. When new mechanists address questions such as scientific explanation, causal inference, or scientific discovery, they intend to provide an answer that applies to all those fields of science where mechanisms are relevant.

5.1. General notions of mechanism

One aspect of the new mechanical philosophy, especially of the new mechanism, that illustrates the aim of generality is the characterisation of mechanisms. The search for generality is present in most current notions of mechanism. New mechanists consider that an appropriate notion of mechanism should be suitable for most of the fields where mechanisms are relevant. And consequently, they aim to develop a general notion that encompass the diverse kinds of mechanisms. This aspect of the new mechanical approach is discussed in “The Search for Generality in the Notion of Mechanism” (annex 1).

In spite of the fact that the search for generality is a trait shared by current characterisations of mechanisms, it is not always pursued with the same strategy. Within the new mechanical philosophy, there are two strategies for developing general notions of mechanism: the extrapolation strategy and the across-the-sciences strategy. The *extrapolation strategy* consists of developing a notion of mechanism taking one or a few fields of science as reference, and then applying that notion to many other fields. This strategy goes from a particular kind of mechanisms to a general notion of mechanisms. MDC (2000), for example, follow the extrapolation strategy. Their notion of mechanism was developed taking neurobiological and molecular mechanisms as guide. Nevertheless, they consider that that notion suits many other fields of science: “We suspect that this analysis is applicable to many other sciences, and maybe even to cognitive or social mechanisms” (Machamer et al., 2000, p. 2). The extrapolation strategy has also been adopted by other authors such as Glennan (1996, 2002) and Woodward (2002).

On the other hand, the *across-the-sciences strategy* consists of thinking about mechanisms across all the sciences and developing a notion of mechanism that includes their common features. This strategy goes from all mechanisms to a general notion of mechanism. The across-the-sciences strategies was introduced by Illari and Williamson (2012). Their aim is to consider mechanisms in general and to propose “a characterization that gives an understanding of what is common to mechanisms in *all* fields” (Illari & Williamson, 2012, p. 120). The across-the-sciences strategy has recently been adopted by Glennan (2017). He has abandoned his previous notion of mechanism (see section 3), and proposes a minimal characterisation, which tries to include what all mechanisms share in common.

The search for generality is very reasonable. There are many kinds of mechanisms in science (e.g. social mechanisms, neural mechanisms, evolutionary mechanisms, etc.). A notion that could account for all of them would be useful for both scientific research and philosophical understanding. It would facilitate the collaboration between fields of science where mechanisms are relevant. Furthermore, a consensus notion of mechanism would help to address several philosophical questions (e.g. scientific explanation). Nonetheless, both suggested strategies for pursuing generality face outstanding difficulties.

The main problem of the extrapolation strategy is that those notions of mechanism which are developed taking certain kind of mechanisms as reference do not suit many other kinds of mechanisms. In order to address the difficulties of the extrapolation strategy, MDC’s proposal (see section 3) is taken as reference. As it has been noted, MDC consider that their notion of mechanism could be applied to most fields of science. However, it is unlikely to be the case. For instance, MDC’s notion is unable to account for economic mechanisms. A well-known example of economic mechanism is monetary transmission mechanisms. A monetary transmission mechanism is a mechanism responsible for the influence of a central bank in output, employment, prices, and inflation of a country or a political and economic union (Samuelson & Nordhaus, 2010, p. 484). It could seem that MDC’s notion suits them, but it is hardly the case.

MDC affirm that mechanisms are regular. Lane DesAutels (2016) has showed that in order to meet their requirement of regularity a mechanism has to be process regular and not be affected by internal sources of irregularity. Nonetheless, monetary transmission mechanisms are not process regular and are affected by internal sources of irregularity. Component entities of monetary transmission mechanisms (e.g. central banks) do not always behave in the same way. Moreover, changes in their components are often the result of internal sources, e.g., changes in decision-making bodies.

Another aspect of MDC's proposal that does not suit monetary transmission mechanisms is the fixation of mechanisms' boundaries. Craver (2007) holds that a mechanism of certain phenomenon is composed of those entities, activities, and organisational features that are part of the system whose behaviour is the phenomenon of interest and are relevant for that phenomenon. Nevertheless, that idea does not suit monetary transmission mechanisms. A monetary transmission mechanism is a mechanism of certain phenomenon, i.e., the influence of a central bank in output, employment, prices, and inflation. However, it is not composed of all entities, activities, and organisational features that are part of the system (e.g. a country) whose behaviour is the phenomenon of interest and are relevant for that phenomenon.

Regarding the across-the-sciences strategy, the main problem is that notions of mechanism are vacuous and overly broad. In order to discuss the difficulties of the across-the-sciences strategy, Illari and Williamson's proposal (see section 3) is taken as reference. Illari and Williamson's definition of mechanism relies on the concepts of entity, activity, organisation, and being responsible for. However, they do not properly characterise those concepts. They offer neither a definition of those concepts nor a set of necessary or sufficient conditions to be certain kind of component. Consequently, the notion become vacuous. Its scope is increased at the cost of decreasing its precision. Moreover, Illari and Williamson's notion is overly broad. Although they consider that their characterisation "is not so broad that it captures non-mechanisms" (Illari & Williamson, 2012, p. 129), it subsumes things that could hardly be accepted as mechanisms. For instance, their notion would admit a group of babies napping as a mechanism.

The aim of Illari and Williamson is to develop a wide notion of mechanism that could encompass mechanisms in all fields. However, even though it seems that they are willing to decrease the precision of their notion in order to increase its scope, their notion is unhelpful to account for several kinds of mechanisms. It does not avoid the problem of the extrapolation strategy. For example, it cannot account for economic mechanisms. Illari and Williamson, as MDC, claim that a mechanism for a phenomenon is composed of those components (entities, activities, and organisation features) that are relevant for it. However, as it has been noted, this idea does not suit economic mechanisms' boundaries.

The difficulties faced by the search for generality in the notion of mechanism undermine a frequent argument in support of the new mechanical account of scientific explanation.[5] It is often claimed that the new mechanical account of scientific explanation is able to encompass explanations across the sciences (Hedström & Ylikoski, 2011). Since mechanisms are relevant in many fields, new mechanists argue that a mechanical approach to explanation could be endorsed in most fields of science. This idea also favours the mechanical account over other alternatives. For example, a well-known problem of the covering-law model is that there are fields of science where only a few laws are known, such as evolutionary biology (see Scriven, 1959; Beatty, 1995). A nomological account of explanation could hardly be adopted in those fields. However, many mechanisms are often known in those fields where laws are not available. The mechanical account would be more broadly applicable than nomological alternatives.

That usual argument relies on the assumption that the same notion of mechanism exists in all fields where mechanisms are relevant. Thus, it is considered that the mechanical account of scientific explanation could offer a unified account of explanation because in several fields of science phenomena could be explained by means of referring to mechanisms. But this would be a unified standpoint only if mechanisms are similarly understood in all fields. If those fields understood mechanisms in a very different way, the mechanical account of scientific explanation would hardly be unifier. Nonetheless, that fundamental assumption—i.e., mechanisms are similarly understood in all fields—is challenged by the difficulties faced by the search for generality. The search for generality constitutes the real attempt of identifying that shared conception of mechanism. New mechanists try to propose a notion of mechanism that suits most fields where mechanisms are relevant. However, as it has been argued, all strategies for pursuing generality face outstanding difficulties. This means that the assumption that the same notion of

[5] The non-success of the search for generality also undermines other proposals related with the new mechanical philosophy. For example, it challenges the claim that the new mechanical approach can provide a framework for interfield integration. See Pérez-González (in press) for a discussion of a particular case, i.e., the mechanism-based integration of neuroscience and social science.

mechanism is shared by all fields is not justified and requires additional support. Not only that shared notion is unknown, but also many attempts of achieving it have failed.

5.2. Mechanical approaches to evolutionary biology

A field of science where the mechanical approach and the application of general notions of mechanism are especially controverted is evolutionary biology. Evolutionary biologists sometimes talk about evolutionary causes as mechanisms. For example, it is said that natural selection "is a powerful mechanism of evolution" (Herron & Freeman, 2014, p. 227) and that it "is an effective mechanism for producing adaptation" (Bell, 2008, p. 499). Following this use, new mechanists have tried to develop a mechanical account of evolutionary causes. In "Evolutionary causes as mechanisms: a critical analysis" (annex 2), Victor J. Luque and I analyse current mechanical approaches to causal evolution, which mainly focus on natural selection, and explore their validity for accounting for evolutionary causes. We identify and discuss three different approaches: the stochastic view, the functional view, and the minimalist view. The former two are related to the extrapolation strategy, while the latter exemplifies the across-the-sciences strategy.

The *stochastic view* is based on the idea that, since natural selection is stochastic, it could be possible to account for it as a mechanism by means of a stochastic version of current notions of mechanism. It is considered that by lowering the demands of regularity it is possible to understand natural selection as mechanism in a sense close to that posed by MDC (2000) and Glennan (2002). The main advocate of the stochastic view is Benjamin Barros (2008). He distinguishes between biased stochastic mechanisms—i.e., stochastic mechanisms that give a result a probability greater than 50%—and unbiased stochastic mechanisms. And he considers that natural selection can be understood as a biased stochastic mechanism. Nevertheless, Barros' account of natural selection faces relevant difficulties. Some of those difficulties are related with the characterisation of natural selection at the population level. Barros considers that natural selection is a two-level mechanism; it involves both the individual and the population level. And he claims that, at the population level, natural selection has populations as component entities. But understanding natural selection as a mechanism whose component entities are populations gives rise to several problems. Firstly, it identifies the subject of the overall phenomenon of the mechanism with the components of the mechanism. And secondly, it entails accepting that a real concrete system—a mechanism of natural selection—is composed of abstract entities—populations—and their relations.

It could be thought that a different stochastic approach, which eludes the diverse problems of Barros' proposal, could correctly account for natural selection and the other evolutionary causes. However, it is unlikely to be the case. Every attempt of understanding evolutionary causes as mechanisms by means of a stochastic approach would rely on the assumption that those causes are stochastic. And that idea also seems problematic. The stochastic character of natural selection and other evolutionary causes (e.g. mutation) is not sufficiently supported, especially from the mathematical apparatus of population genetics. In population genetics, most evolutionary causes are usually modelled in a deterministic way. Furthermore, biological practice also casts doubt on the stochastic interpretation of some evolutionary causes. When biologists deal with real populations, they often understand evolutionary causes such as natural selection, migration, and mutation in a deterministic way (e.g. Dobzhansky & Pavlovsky, 1957). They consider that the stochasticity of populations' evolutionary paths is mainly a product of genetic drift.

The *functional view*, inspired by functional approaches to mechanisms (e.g. Bechtel & Abrahamsen, 2005), aims to characterise natural selection as an MDC mechanism. It is considered that natural selection performs a function—i.e., to produce adaptation—and that it provides the basis for addressing the mechanism of natural selection. Illari and Williamson (2010) argue that, insofar as it has a function, natural selection can be decomposed into organised entities and activities. They consider that components of a mechanism can be identified and individuated on the basis of their function, i.e., their contribution to the function of the mechanism as whole. Therefore, since natural selection has the function of producing adaptation, it is decomposable into entities (e.g. organisms) and activities (e.g. reproduction) that contribute to it. Illari and Williamson also consider that by taking as reference the function of a mechanism it is possible to attribute organisation to it. They define organisation as "whatever features exist by which the activities and entities each do something and do something together to produce the phenomenon" (Illari & Williamson, 2010, p. 289). Natural selection, insofar as it has a function, is an organised mechanism too. Taking the functional approach to natural selection and the theses defended by Illari and Williamson as reference, DesAutels (2016) argues that natural selection also meets MDC's requirement of regularity. Natural selection is process regular and its regularity is not threated by internal sources. DesAutels claims that “natural selection only fails to be regular in ways that are unthreatening to its status as MDC mechanism” (DesAutels, 2016, p. 16). Not always producing the same output and being susceptible to external sources of irregularity do not severely undermine its regular nature.

The main problem of the functional view is related with the function attributed to natural selection. Advocates of the functional view consider that producing adaptation is the primary function of natural selection. This is the cornerstone of their approach and all their arguments ultimately rely on it. Nevertheless, that idea is very problematic. Natural selection does not necessary increase adaptation. It is just a potential (but not necessary) outcome of the process of natural selection (Gould & Lloyd, 1999). Natural selection ultimately acts on reproductive efficacy [*fitness*], although it may also indirectly influence other traits such as the capacity to adjust to a particular environment (Gillsepie, 2004). It invariably leads to non-random reproductive success, but not always leads to adaptation.

The functional view would also face relevant difficulties for accounting for other evolutionary causes. It would require assigning functions to those causes. However, each evolutionary cause brings about several outcomes and it is difficult to identify one of them as its function. For example, migration introduces genetic variation in a population, reduces the level of differentiation among populations, favours hybridization, etc. The functional view would also have difficulties for identifying and delimiting evolutionary mechanisms. As it has been noted, a mechanism is always a mechanism for a phenomenon (see section 3). And the defenders of the functional view consider that a mechanism is composed of those entities, activities, and organisational features that contribute to the phenomenon for which the mechanism is responsible. It means that the mechanism responsible for each phenomenon or outcome is different. Consequently, from their proposal, the mechanism responsible for each outcome attributed to a particular evolutionary cause would be a different one. However, that consideration does not suit evolutionary biologists’ ideas; they consider that the *same* particular evolutionary process is responsible for all those outputs.

Finally, the *minimalist view* consists of directly applying in evolutionary biology a general notion of mechanism developed by means of the across-the-sciences strategy. Glennan (2017), for instance, proposes a minimal characterisation which aims to include what all mechanisms share in common. He considers that that minimal definition is “broad enough to capture most of the wide range of things scientists have called mechanisms” (Glennan, 2017, p. 18), including evolutionary mechanisms. Certainly, Glennan's minimal notion includes general characteristics that are often present in mechanisms (e.g. organisation). Nonetheless, his proposal does not take into consideration the specific traits of evolutionary mechanisms and can hardly account for them. For example, Glennan's notion of mechanism's component entity (or part) does not suit evolutionary causes' parts. He claims that entities must be stable. The stability required depends on the mechanism in which they are involved. A component entity of a mechanism is stable enough if its properties and boundaries remain stable while the phenomenon for which that mechanism is responsible is taking place. Nonetheless, the application of that requirement to evolutionary causes' parts would be problematic. Firstly, as it has been discussed, evolutionary causes are responsible for several phenomena with different timescales. Consequently, it would be very difficult to determine which degree of stability must be required to an entity. And secondly, properties of parts of evolutionary causes do not always remain stable while those causes and phenomena for which they are responsible are taking place. For example, as a result of phenotypic plasticity, the colour or the height of an individual organism may change during a process of migration (Pigliucci, 2001).

5.3. Mechanistic explanations in social science

The aim of generality of the new mechanical philosophy faces important difficulties. As it has been shown, the new mechanical approach can hardly account for mechanisms and their roles in some fields of science. Mechanisms (and the roles they play) differ significantly from one field to another. So, general considerations that overlook that heterogeneity are often problematic. Given this scenario, it seems that, in order to address a methodological question, it is crucial to take into account the specific traits of the scientific field (or fields) of interest. This approach is adopted in "Mechanistic explanations and components of social mechanisms" (annex 3). In that paper, I discuss some aspects of mechanism-based explanations in social science taking social scientists' practice as my main source. In particular, I address the question of what the components of social mechanisms in mechanistic explanations of social macro-phenomena must be (henceforth, "the question of components").

The question of components has been mainly addressed within the framework of analytical sociology. A core idea of analytical sociology is the principle of mechanism-based explanations (Hedström, 2005; Hedström & Bearman, 2009; Hedström & Ylikoski, 2011). As it has been noted in section 3, analytical sociologists advocate the mechanistic account of scientific explanation. They consider that a social macro-phenomenon is explained by specifying the mechanisms by which that phenomenon is brought about. The other fundamental principle of analytical sociology is structural individualism (Hedström, 2005; Hedström & Ylikoski, 2010; Hedström & Ylikoski, 2011). It is a weak version of methodological individualism. Structural individualism considers that social macro-phenomena must be explained in terms of interactions of individual agents. However, unlike other versions of methodological individualism, it admits that not all explanatory facts are about individuals in the strict sense. Relations and relational structures can be explanatorily relevant.

The principles of mechanism-based explanations and structural individualism are not considered independent. It is held that the principle of mechanism-based explanations implies structural individualism. The main argument in support of that idea is that there are social mechanisms only at the individual level (Hedström & Swedberg, 1998b; Hedström, 2005). Putting the matter in other words, demanding mechanistic explanations in social science means demanding explanations in terms of individuals, their properties, actions, and relations. Consequently, supporting a mechanistic account of explanation in social science would require a commitment to structural individualism. The adoption of structural individualism leads to an answer to the question of components: a social mechanism in an explanation of a social macro-phenomenon must be composed of individuals, their properties, actions, and relations to one another. This is the initial position of analytical sociology regarding the question of components.

In response to analytical sociology's initial answer to the question of components, several authors have disputed the idea that the principle of mechanism-based explanations implies structural individualism (Vromen, 2010; Kaidesoja, 2013). They have argued that it is unlikely to be the case that all social mechanisms are at the individual level. There are social mechanisms that have components of a higher level, e.g., a coalition between political parties. Therefore, analytical sociologists' main argument in support of the implication between both principles would not hold and, consequently, their initial position regarding the question of components would not be justified.

Given the critiques against their initial position regarding the question of components, different answers have been raised by analytical sociologists. Michael Schmid (2011) presents a new argument in support of analytical sociology's initial position. He also adopts the principle of structural individualism, which leads to that position, but his argumentation does not rely on the idea that there are social mechanisms only at the individual level. Firstly, Schmid claims that one aspect of mechanism-based explanations in social science is that they require "*laws* indicating which factors ultimately 'produce' or 'generate' a relevant event" (2011, p. 137). Specifying nomological connections is necessary in mechanistic explanations. And secondly, he argues that, strictly speaking, we do not know any social law, i.e., a law governing the course of social macro-processes. In social science, only laws of individual action are available. From those premises, Schmid concludes the principle of structural individualism regarding mechanism-based explanations. Structural individualism, as it has been noted, leads to the analytical sociology's initial position.

Schmid's new argument is valid. The truth of the premises supports the truth of the conclusion. If its premises were true, it would follow the principle of structural individualism. Nonetheless, one of the premises of the argument is probably not true. The first premise, which is supposed to present a trait of mechanism-based explanations, is unlikely to be accurate. Mechanistic explanations are not required to include laws (Halina, 2018). In a mechanistic explanation, the explanandum is explained by uncovering the mechanism that is responsible for it, and specifying laws is not required for that. It is not necessary to show that those activities in which its component entities are engaged instantiate laws. For instance, consider Mann's (2004) mechanism-based explanation of the property of certain countries (e.g. Britain) in the interwar period of not being susceptible to fascists movements seizing power. He refers to a mechanism whose main components are the political parties of those countries and some of their properties (e.g. being accustomed to relinquishing sovereign powers). However, no nomological connection between political parties' properties and countries' susceptibility to fascists movements seizing power is specified.

Petri Ylikoski (2012), unlike Schmid, advocates a modified version of analytical sociology's initial position regarding the question of components. Ylikoski (2012, 2013) considers that mechanism-based explanations of social macro-phenomena can be causal or constitutive. And taking that distinction as reference, he addresses the question of components. Firstly, Ylikoski discusses constitutive mechanistic explanations of social macro-phenomena. He considers that "[t]he *explanantia* in constitutive explanations are always at the micro level" (Ylikoski 2012, p. 35). Therefore, he claims that the components of social mechanisms in constitutive mechanism-based explanations must be located at the micro level. Secondly, Ylikoski addresses causal mechanistic explanations of social macro-phenomena. He acknowledges that the explanantia in causal explanations are not always at the micro level. Nevertheless, he considers that causal mechanistic explanations of social macro-phenomena require “microfoundations”. Appealing to micro-level entities, properties, activities, and relations is essential for understanding how the causal counterfactual dependencies hold. Consequently, he argues that the components of social mechanisms in causal mechanism-based explanations must be located at the micro level. Ylikoski concludes that, in (constitutive and causal) mechanism-based explanations of social macro-phenomena, social mechanisms must be composed of micro-level entities, properties, activities, and relations.

Ylikoski’s proposal is less rigid that the analytical sociology’s initial position regarding the question of components. He holds that components of social mechanisms must be micro-level entities, properties, activities, and relations. Nonetheless, he considers that there is not a unique and predetermined micro level. The micro-macro distinction is understood as a question of scale. What is considered as a micro-level component depends on the explanandum phenomenon (and also on the explanatory interests). Ylikoski’s perspectival proposal avoids the main difficulties of analytical sociology’s initial approach—it is compatible with the fact that not all social mechanisms are at the individual level—and Schmid’s argument—it does not require that mechanistic explanations include laws. Nevertheless, it also faces some relevant difficulties.

The main problem of Ylikoski’s proposal is that it is too vague and, consequently, does not constitute a proper answer to the question of components. The notion of ‘micro level’ is not accurately characterised. The micro-macro relation is defined as a particular kind of difference in scale, but the traits that characterise and distinguish it from other differences in scale are not clearly specified. Another problematic aspect of Ylikoski’s proposal is that it does not provide a guide for building mechanism-based explanations. On the one hand, as it has been noted, it is not concrete enough. It is never certain if a particular component is at the micro level. And on the other hand, the identification of the micro level would require the previous specification of the explanans and the explanandum. In order to belong to the micro level, a component must be explanatorily relevant for the explanandum macro-phenomenon. Finally, Ylikoski’s proposal does not suit many mechanism-based explanations of social macro-phenomena. The fact is that in social science, causal mechanistic explanations of social macro-events often include entities, properties, activities, or relations that are unlikely to be at the micro level. For example, consider McCright and Dunlap’s (2003) mechanism-based explanation of the no ratification of the Kyoto Protocol by the United States senate. They specify how conservative think tanks (and their collaboration with climate change sceptics) produced the redefinition of global warming as non-problematic, and how that redefinition influenced in the policy arena and brought about the no ratification of the protocol. In McCright and Dunlap's explanation, most components of the social mechanism (e.g. think tanks) are hardly at the micro level regarding the explanandum, i.e., the no ratification of the Kyoto Protocol by the United States senate.

There is no privileged level to which components of social mechanisms in mechanistic explanations of social macro-phenomena must always belong. Neither in causal mechanism-based explanations nor in constitutive mechanism-based explanations of social macro-phenomena, must components of social mechanisms always belong to a certain predetermined level. Given this scenario, it could be considered that a proper answer to the question of components is hardly achievable. It seems that proposals that account for the diversity of mechanistic explanations (as Ylikoski's proposal) are too vague and unable to provide a guide for building mechanism-based explanations, while concrete and operational proposals (as analytical sociology's initial position) do not suit the diversity of mechanistic explanations. Nonetheless, I think that a minimal requirement, which is concrete and operational without neglecting the diversity of mechanism-based explanations, can be raised regarding the components of social mechanisms. Particularly, a component of a social mechanism in a mechanistic explanation of a social macro-phenomenon must not have the explanandum phenomenon as a part of it.

The minimal requirement applies to both causal and constitutive mechanistic explanations of social macro-phenomena. In causal mechanism-based explanations, components of the mechanism must not have the explanandum phenomenon as a part of them. To be a component of the mechanism, an entity or an activity (or another kind of component) must be causally relevant for the explanandum phenomenon. However, there cannot be a relation of causal dependence between them if the entity or activity has the explanandum phenomenon as a part of it. A relation of causal dependence between a whole and one of its parts is not possible (Hitchcock, 2003; Craver & Bechtel, 2007). Likewise, in constitutive mechanism-based explanations, the explanandum phenomenon must not be included among the components of the social mechanism. In that kind of explanations, components of the mechanism must be proper parts of the system whose property or behaviour is the explanandum phenomenon (Craver, 2007). Nevertheless, a component cannot be a proper part of the system whose property or behaviour is the explanandum phenomenon if that phenomenon is part of it. If the phenomenon of interest is part of a component, the system whose property or behaviour is that phenomenon is also part of this component. And if the system is part of the component, the component cannot be a proper part of the system.

6. Mechanistic explanations and science denialism

Science denialism is a well-known form of pseudoscience. Unlike pseudotheory promotion, science denialism does not focus on promoting a specific theory (e.g. the principle of similars, i.e., like cures like), but on denying certain scientific claim. Science denialism consists in the systematic rejection of a claim on which a scientific consensus exists (Diethelm & Mckee, 2009; Liu, 2012; Hansson, 2017). It is usually targeted at scientific claims that damage people's lifestyle or worldviews, or that threat corporate interests (Lewandowsky et al., 2016). Some prominent examples are tobacco disease denialism, evolution denialism, and climate change denialism.

Although it is hardly a homogeneous movement, there are five epistemological traits that characterise every case of science denialism (Liu, 2012; Hansson, 2017, 2018). First, cherry-picking of data is systematically employed in the argumentations, so that only a small part of the available evidence is considered. Second, denialists are reluctant to give up ideas and arguments even if they have been refuted. Third, fake controversies are fabricated. It is held that a certain issue is subject to a genuine scientific controversy, although an overwhelming consensus exists among scientists. Fourth, deviant criteria of assent are introduced. Denialists set unrealistic standards for evidence, which can hardly be met by current scientific research. And fifth, the opposition viewpoint is misrepresented. The scientific claim is distorted, for instance, by taking quotes out of context. There are also several sociological characteristics that are often present in science denialism (Diethelm & Mckee, 2009; Liu, 2012; Hansson, 2017, 2018). For example, science denialism usually has strong political connections (e.g. evolution denialism is related with Christian right wing). Other sociological characteristics that are frequently present in science denialism are: being supported mostly by men, addressing laypeople instead of scholars, and attacking individual scientists personally and professionally.

A relevant kind of science denialism, which has not been previously addressed, is 'explanatory war'. In "Mechanisms and science denialism: explaining the global lung cancer epidemic" (annex 4), that form of pseudoscience is characterised and discussed. An *explanatory war* is a situation in which (i) there is an undisputed phenomenon (e.g.

an increasing incidence of a disease), (ii) in the scientific community there is a broad consensus on its explanation, and (iii) the standard scientific explanation is systematically denied by a group of people. In order to fight down the mainstream science's explanation, two strategies are usually followed by denialists. On the one hand, they directly attack the standard explanation. For instance, they claim that the causal link between explanans and explanandum has not been proved with one hundred percent certainty (Proctor, 2011; Prothero, 2013). On the other hand, denialists propose and promote alternative explanations, which are presented as being as legitimate as the standard explanation, to increase the controversy and make their case more credible (Proctor, 2004, 2011; Pearl & Mackenzie, 2018). For example, they support private research to study every minimally plausible alternative explanation. In explanatory wars, the distinctive traits of science denialism are present. Strategies such as introducing deviant criteria of assent and fabricating fake controversies have a crucial role in the offensive against the standard explanation.

The mechanical account of scientific explanation is helpful to face explanatory wars. In an explanatory war, the standard explanation of a phenomenon is denied by a group of people. However, if the standard explanation is mechanistic, denialists' offensive is less effective. Mechanism-based explanations are resistant to the arguments usually raised by denialists. As it has been noted, in order to fight down the mainstream science explanation, two strategies are followed by denialists. First, they directly attack the standard explanation. Denialists usually argue that the standard explanation does not satisfactorily prove the causal link between explanans and explanandum. Their arguments are based on "an extraordinarily narrow and mechanical conception of causation" (Proctor, 2011, p. 275). Second, denialists propose and promote alternative explanations to increase the controversy. Alternative explanations, which are presented as equally legitimate as the standard explanation, usually rely on statistical correlations between the explanandum phenomenon and variables not included in the mainstream science explanation (Proctor, 2004, 2011). Nevertheless, the strategies followed by denialists are hardly effective against mechanistic explanations. On the one hand, mechanistic explanations establish the (causal or constitutive) link between explanans and explanandum. They show how the phenomenon of interest comes about. On the other hand, alternative explanations raised by denialists would not be legitimate explanations on the same footing than the standard explanation. They are rarely mechanistic explanations, but black-box explanations that do not address the link between explanans and explanandum, and are not supported by the same kind of evidence that supports standard mechanistic explanations.

The relevance of mechanistic explanations and its resistance to denialists' attacks can be illustrated by means of the explanatory war regarding the global lung cancer epidemic. At the beginning of the twentieth century, lung cancer was an extraordinarily rare disease (Proctor, 2001, 2011, 2012). Only a few hundred cases had been reported in the world medical literature. However, during the first decades of the twentieth century, an increased incidence of lung cancer was noticed in several countries. This dramatic change in the incidence of lung cancer begged for an explanation. During the following decades, several possible explanations of the epidemic were discussed. Among the diverse factors that were taken into account were atmospheric pollution, occupational exposures, and the growing popularity of cigarettes (Proctor, 2004, 2011). Finally, in the 1950s, the idea that tobacco consumption explained the lung cancer epidemic took the lead. The causal link between cigarettes and lung cancer was established by four direct lines of evidence: population studies, animal experimentation, cellular pathology, and chemical analytics (Proctor, 2012). And, as a result of this causal knowledge, a broad consensus emerged among experts that tobacco consumption accounted for the global lung cancer epidemic (Proctor, 2011, 2012).

By the mid-1950s, there was a consensus among scientists that tobacco consumption explained the lung cancer epidemic. Nevertheless, the tobacco industry systematically denied that explanation. Although they accepted that the frequency of lung cancer had increased and that this required an explanation, they rejected the explanation that linked the lung cancer epidemic with their product. In order to fight down the mainstream science explanation, the tobacco industry followed two strategies. Firstly, they attacked the standard explanation (Proctor, 2011). Their main argument was that the causal link between tobacco and lung cancer was not conclusively established and more research was necessary. Secondly, the tobacco industry promoted alternative explanations of the global lung cancer epidemic (Proctor, 2004, 2011). By means of institutions such as the Council for Tobacco Research and the Tobacco Institute, they funded and publicised research focused on investigating possible causes of lung cancer other than tobacco.

In the early 1990s, the mechanisms that link smoking cigarettes and lung cancer were discovered. The standard explanation of the lung cancer epidemic became a mechanistic explanation (Russo & Williamson, 2007). It detailed the processes though which smoking brings about lung cancer. As a result, the tobacco industry's strategies lost their effectiveness. On the one hand, the standard scientific explanation conclusively stablished the causal link between smoking and lung cancer. It suited the narrow mechanical account of causation adopted by denialists and made the 'more research' argument obsolete. On the other hand, the standard explanation clearly distinguished itself from the alternative explanations. It was a causal mechanistic explanation, while the alternatives were statistical or non-mechanistic causal explanations. In the 1990s, after that loss of effectiveness, the tobacco industry changed its strategy and stopped denying the mainstream science explanation of the lung cancer epidemic (Proctor, 2001, 2006, 2011). They accepted that tobacco was a risk factor in the development of lung cancer and that tobacco consumption explained the high incidence of lung cancer. From that point on, their legal strategy was to argue "that the risks of smoking have been well-known for decades, and that people therefore voluntarily assume such risks when they take up the habit" (Proctor, 2001, p. 84).

7. Conclusions

Mechanisms have a central role in the scientific enterprise. From molecular biology to sociology, scientists in diverse fields appeal to mechanisms to describe, explain, predict, and control worldly phenomena. The relevance of mechanisms and mechanism-based approaches has not gone unnoticed for philosophers. As it has been noted, the first mechanical philosophy dates back to the Classical Greece. The mechanical philosophy enjoyed great popularity during the second half of the seventeenth century. In that period, the mechanical philosophy became the dominant approach in natural philosophy and philosophy of science. Nevertheless, although less influential, several mechanical accounts have subsequently been advocated in philosophy.

In the current philosophical debate, the new mechanical philosophy is the main representative of the mechanical approach. Like the seventeenth-century mechanical philosophy, it is both a philosophy of science and a philosophy of nature. The new mechanical philosophy is not only concerned about the scientific methodology, but also about the constitution and organisation of the world. It is considered that mechanisms are one of the main constituents of the world. Nonetheless, as it has been noted, the new mechanical philosophy is characterised by a general emphasis on actual scientific practice. Its primary object of interest is mechanism as a concept-in-use in science. The new mechanists focus on scientific practice and take it as the main reference for addressing both methodological and ontological questions.

The new mechanical philosophy has proven to be a very fruitful approach in philosophy of science. It has led to significative progress in several philosophical discussions. Within the framework of the new mechanical philosophy, it has been convincingly addressed scientific explanation (Machamer et al., 2000; Bechtel & Abrahamsen, 2005), causal inference (Steel, 2004; Russo & Williamson, 2007; Parkkinen et al., 2018), extrapolation of causal claims (Steel, 2008; Wilde & Parkkinen, 2019), scientific inquiry (Bechtel & Richardson, 1993; Darden, 2018), knowledge growth and organization (Hedström & Ylikoski, 2010; Glennan, 2017), and several other questions. As it is argued in "Mechanisms and science denialism: explaining the global lung cancer epidemic" (annex 4), the new mechanical philosophy could also contribute to combat pseudoscience. The new mechanical approach is helpful to deal with some forms of science denialism. It is particularly valuable in explanatory wars. The new mechanical account of scientific explanation provides explanations resistant to the arguments usually raised by denialists. Furthermore, the new mechanical philosophy offers a promising approach for addressing other relevant problems such as risk assessment (Rocca, 2017; Rocca et al., 2020), public understanding of science (Lewandowsky & Oberauer, 2016), and ethical and welfare evaluation (Grüne-Yanoff, 2016).

Nevertheless, the new mechanical philosophy also has certain problematic aspects. Some of those deficiencies are related with its aim of generality and broad applicability. Mechanisms are relevant in most scientific fields, and the new mechanical philosophy aims to provide a general mechanical approach that encompasses all of them. Nonetheless, it faces important difficulties for accounting for mechanisms and their roles in some fields. One of those difficulties, which is addressed in "The Search for Generality in the Notion of Mechanism" (annex 1), concerns the notion of mechanism itself. New mechanists intend to develop a general notion of mechanism appropriate for the whole range of mechanisms studied across the sciences. The development of a general notion is pursued with diverse strategies―i.e., the extrapolation strategy and the across-the-sciences strategy. However, all of them have proved unsuccessful. They are unable to provide a notion of mechanism able to satisfactorily account for all kinds of mechanisms. Moreover, it is doubtful that an appropriate general notion of mechanism could be developed. The phenomena, entities, activities, and organisational aspects studied by different sciences are so heterogeneous that a notion of mechanism that is informative and covers all the relevant cases seems unattainable.

One of the main advancements of the new mechanical philosophy is to pay attention at current scientific practice. Considering mechanism as a concept-in-use in science has been crucial for most of its contributions (e.g. analysing scientific discovery). Nevertheless, the new mechanical philosophy seems to fail to acknowledge the relevant differences among scientific fields. It does not take into consideration the particularities of mechanisms and their roles in each area. Consequently, the new mechanical approach faces important difficulties for being broadly applied. For instance, as it is extensively discussed in "Evolutionary causes as mechanisms: a critical analysis" (annex 2), ignoring the particularities of evolutionary mechanisms render inadequate the mechanical approaches to evolutionary biology. To overcome those difficulties, the new mechanical philosophy should give up the naïve assumption of sameness and consider the specificity of scientific fields. When a methodological question is addressed, a field-specific approach should initially be adopted. In each relevant field, the question should be addressed taking as the main reference the practice of the involved scientists. Considering scientific practice is not enough, it is necessary to consider the pertinent scientific practice. This field-specific approach is adopted in "Mechanistic explanations and components of social mechanisms" (annex 3). In this paper, taking social scientists' practice as the main source, it is addressed the questions of what the components of social mechanisms in mechanistic explanations of social macro-phenomena must be.

The field-specific approach would facilitate the application of the new mechanical philosophy to additional fields of science. There are scientific fields that significantly differ from those initially considered by the new mechanists and whose particularities should be considered. This is the case, for example, of psychology (Kazdin, 2007; Koch & Cratsley, 2020). The mechanisms studied by psychologists are different to biological and social mechanisms in many relevant aspects. Furthermore, the field-specific orientation would enable the new mechanical approach to successfully address field-specific problems, such as generalising from case studies in social science (Ylikoski, 2019).

Recognising the diversity of scientific fields regarding how mechanisms are understood and what roles they (could) play does not mean to renounce to the aim of generality. The new mechanical philosophy could develop an encompassing mechanical approach that suits all those fields in which mechanisms are relevant. In fact, that kind of approach would be very fruitful for addressing general philosophical questions and facilitating collaboration between fields. Admitting the specificity of scientific fields just means that general claims cannot overlook how mechanisms and their roles are considered in the diverse areas of science. The encompassing mechanical approach must be built on the basis of the field-specific discussions of mechanism as a concept-in-use.

Resumen

1. Mecanismos en la ciencia

En la literatura científica, frecuentemente se apela a mecanismos. Cientos de artículos que hacen referencia a mecanismos son publicados cada año en revistas como *Nature*, *Science* y *The Lancet*. La terminología mecanicista se extiende a lo largo de todo el espectro científico, no es exclusiva de unas pocas áreas. Los científicos discuten sobre "mecanismos reguladores", "mecanismos de acción", "mecanismos de asignación", "mecanismos de selección", "mecanismos de supresión", etc. en muy diversos campos. Ciertamente, parece que los mecanismos juegan un papel importante en la empresa científica. No obstante, esto no es excesivamente sorprendente. Los principales objetivos de la ciencia son describir, explicar, predecir y controlar fenómenos del mundo. Y los mecanismos son relevantes para alcanzar esos objetivos. Ellos revelan *como* los fenómenos del mundo —el objeto de interés de la investigación científica— son constituidos o producidos.

A fin de ilustrar la relevancia de los mecanismos, considere la desigualdad de éxito en los mercados culturales. Los productos culturales exitosos (p. ej. los libros superventas) son varias veces más exitosos que la media. Mas de cien millones de copias de *Harry Potter and the Philosopher's Stone* —el primer libro de la saga Harry Potter— se han vendido desde su publicación en 1997, mientras que la mayoría de los autores solo logran vender unos pocos cientos de copias de sus apreciados manuscritos. De modo similar, *Avatar* recaudó 749 millones de dólares en el mercado doméstico, más de cuarenta y siete veces la recaudación media en los EUA en 2010. La explicación que el sentido común da a esta desigualdad apela a propiedades intrínsecas de los productos exitosos (p. ej. la estructura narrativa) (Watts, 2011). Tendemos a considerar que esos productos son cualitativamente diferentes a sus pares y que esa diferencia es la responsable de su éxito arrollador. Sin embargo, esa explicación se ve socavada por la impredecibilidad de los mercados culturales. Incluso los expertos son a menudo incapaces de determinar con antelación que productos triunfarán. De hecho, *Harry Potter and the Philosopher's Stone* fue rechazado por doce editores antes de ser aceptado para su publicación (Gunelius, 2008).

Por tanto, para poder dar adecuadamente cuenta de la desigualdad de éxito en los mercados culturales, es crucial identificar el mecanismo responsable de ella. Los sociólogos Salganik, Dodds y Watts (Salganik et al., 2006; Salganik & Watts, 2009a, 2009b) han estudiado como el comportamiento (no independiente) de los consumidores individuales conduce a la desigualdad de éxito. La influencia social está presente en los mercados culturales, donde a menudo se dispone de información sobre el éxito de los productos ofertados (p. ej. listas de los libros más vendidos). Debido a la gran cantidad de productos culturales ofertados, los individuos suelen seguir las elecciones tomadas por otros y comprar esos productos que ya son populares. Esta tendencia se ve reforzada por rasgos estructurales de muchos mercados culturales, como dar a los libros más vendidos un lugar más prominente en la tienda. En consecuencia, la ventaja acumulativa opera. Los productos culturales exitosos tienden a ser aún más exitosos. Las pequeñas diferencias iniciales se hacen mayores y, como resultado, la desigualdad aumenta. En el trabajo de Salganik, Dodds y Watts, la presencia de la influencia social en los mercados culturales y su contribución a la desigualdad de éxito son avaladas por estudios experimentales en mercados culturales artificiales (véase Salganik et al., 2006; Salganik & Watts, 2009b).

El rol central de los mecanismos también se manifiesta en la práctica de la International Agency for Research on Cancer (IARC). El objetivo de la IARC es preparar y publicar revisiones y evaluaciones de la evidencia sobre la carcinogenicidad de determinados agentes (p. ej. exposiciones ambientales) (IARC, 2019). En base a la evidencia disponible, busca establecer en qué medida esos agentes pueden ser considerados cancerígenos para los humanos. La evaluación de los agentes está informada por tres tipos de evidencia: evidencia de cáncer en humanos, evidencia de cáncer en animales y evidencia de mecanismos. En este contexto, la evidencia de mecanismos refiere principalmente a información sobre toxicocinética (p. ej. metabolización) y procesos de carcinogénesis (p. ej. inducir alteraciones epigenéticas). Tras analizar individualmente cada estudio y abordar separadamente cada tipo de evidencia en su conjunto, los tres tipos de evidencia son integrados en una evaluación global de la carcinogenicidad del agente. Después, de acuerdo con esa evaluación, el agente es clasificado como cancerígeno para los humanos, probablemente cancerígeno para los humanos, posiblemente cancerígeno para los humanos o no clasificable de acuerdo con su carcinogenicidad para los humanos.

En la evaluación global de los agentes, el principal rol de la evidencia de mecanismos es guiar la extrapolación de relaciones causales de modelos animales a humanos (Leuridan & Weber, 2011). Cuando la evidencia de cáncer en humanos es limitada o inadecuada, la evidencia de mecanismos es necesaria para determinar si el agente es cancerígeno para los humanos. Este rol de la evidencia de mecanismos fue crucial en la evaluación del benzo[a]pireno (IARC, 2012), la cual ha sido analizada en detalle por Wilde y Parkkinen (2019). Aunque no había evidencia de cáncer en humanos

(p. ej. datos epidemiológicos) disponible, el benzo[a]pireno fue clasificado como cancerígeno para los humanos. Las similitudes identificadas entre los mecanismos que operan en los modelos animales y los que operan en los humanos permitieron la extrapolación de la relación causal. Se consideró que "[t]he strong and extensive experimental evidence for the carcinogenicity of benzo[a]pyrene in many animal species, supported by the consistent and coherent mechanistic evidence from experimental and human studies provide biological plausibility to support the overall classification of benzo[a]pyrene as a human carcinogen" (IARC, 2012, p. 138).

No obstante, es conveniente señalar que la práctica científica a veces no presta suficiente atención a los mecanismos. Un ejemplo de esta negligencia es el desastre de la talidomida (Brynner & Stephens, 2001). A diferencia de lo sucedido en la evaluación del benzo[a]pireno, en este caso la evidencia de mecanismos no fue tenida en cuenta. En la década de 1950, debido a la guerra fría y a las secuelas psicológicas de la segunda guerra mundial, la ansiedad y el insomnio estaban muy extendidos en Europa y los EUA. Los tranquilizantes y las pastillas para dormir se convirtieron en productos de uso diario. Sin embargo, la mayoría esos sedantes era barbitúricos peligrosos y se demandaba una alternativa más segura. En este contexto, Chemie Grünenthal, una empresa farmacéutica alemana, accidentalmente produjo la talidomida. Después de testarla en estudios con animales y no observar efectos secundarios —ninguna dosis era lo suficientemente alta como para matar a los animales—, el equipo de Grünenthal buscó una enfermedad que la talidomida pudiera curar. Pronto descubrieron que la talidomida tenía un efecto calmante e inducía al sueño sin reducir la actividad motora. En octubre de 1957, la talidomida salió al mercado como sedante en Alemania y, en unos pocos meses, estaba disponible en casi cincuenta países de todo el mundo. Se anunciaba como un sedante completamente seguro, el cual era apropiado para niños y mujeres embarazadas. Sin embargo, la talidomida podía producir defectos de nacimiento (p. ej. focomelia) cuando era consumida por mujeres embarazadas. En noviembre de 1961, después de que varios informes la vincularan a defectos de nacimiento, la talidomida fue retirada del mercado en Alemania. En los siguientes meses, fue retirada del mercado en los países restantes. No obstante, se estima que entre 8.000 y 12.000 bebes fueron deformados por la talidomida durante su periodo de comercialización.

Tal y como Donald Gillies (2017) ha señalado, es poco probable que ensayos clínicos aleatorizados (ECA) o más estudios en animales hubieran revelado el potencial de la talidomida para causar defectos de nacimiento. Por un lado, las mujeres embarazadas no pueden participar en los ECA y, por otro lado, la talidomida raramente produce defectos de nacimiento en animales que no sean primates. Sin embargo, considerar la evidencia de mecanismos hubiera revelado el potencial teratogénico de la talidomida y ayudado a evitar el desastre (Gillies, 2017). Primero, analizar el mecanismo de absorción de la talidomida hubiera mostrado que, dado su peso molecular, puede traspasar la placenta y entrar en el feto. Y segundo, comparar los mecanismos que operan en los modelos animales y los que operan en los humanos hubiera revelado las relevantes diferencias entre ellos y cuestionado la afirmación de seguridad.

En resumen, los mecanismos tienen un rol central en la empresa científica. Tal y como evidencian los ejemplos anteriores, los mecanismos son a menudo cruciales para alcanzar objetivos tales como la explicación o la inferencia causal fiable. La ausencia de información sobre los mecanismos puede dificultar severamente la labor de los científicos. En consecuencia, una discusión rigurosa de la metodología científica no puede pasar por alto los mecanismos y sus importantes contribuciones.

2. Filosofías mecanicistas

La relevancia de los mecanismos y de los enfoques basados en mecanismos no ha pasado desapercibida para los filósofos. De hecho, la primera 'filosofía mecanicista' se remonta a la Grecia clásica (c. 500 – c. 323 a. C.) (Popa, 2018).[1] Demócrito de Abdera defendió que el mundo está compuesto por dos tipos diferentes de realidades: átomos y vacío. Los átomos son invisibles, no generados, invariables e indestructibles. Son homogéneos y solo difieren en su forma y tamaño. Por otro lado, el vacío es definido como el absoluto no-ser. Los átomos, los cuales son infinitos en número, se mueven en el vacío infinito y se combinan en diferentes agrupaciones. Los objetos macroscópicos son en realidad agrupaciones de átomos invisibles y sus propiedades dependen de qué átomos los constituyan. Los cambios en esos objetos son resultado de reagrupaciones de los átomos. En el atomismo de Demócrito, se considera que cualquier fenómeno del mundo es explicable en términos de átomos, sus propiedades y sus interacciones (Hankinson, 1998; Popa, 2018). En el periodo helenístico (c. 323 – c. 30 a. C.), la teoría atomista fue adoptada

[1] Berryman (2003) argumenta que no hubo un enfoque verdaderamente mecanicista hasta el periodo helenístico. Ella define un enfoque mecanicista como "a method of investigating the natural world through terms and principles drawn from the discipline called 'mechanics'" (Berryman, 2003, p. 344). Y de acuerdo con esa caracterización, las propuestas mecanicistas no eran posibles antes del desarrollo de la mecánica, el cual tuvo lugar durante el siglo cuarto antes de Cristo. Sin embargo, la idea de Berryman de enfoque mecanicista es demasiado restrictiva y no se ajusta a la concepción contemporánea de los mecanismos.

y desarrollada por los epicúreos. Los epicúreos abordaron aspectos psicológicos como la voluntad o el deseo, y ofrecieron explanaciones mecanicistas de ellos en términos de interacciones entre átomos. Además, los epicúreos reivindicaron "the value of atomist theory for teaching us how to live the untroubled and tranquil life" (Berryman, 2016).

En la filosofía natural antigua, el mecanicismo atomista fue criticado por los defensores de las explicaciones teleológicas. Estos autores consideran que los fenómenos naturales deben ser explicados haciendo referencia a funciones, objetivos o finalidades. No obstante, las analogías tecnológicas o de artefactos eran ocasionalmente usadas por ellos como recursos explicativos (Berryman, 2003). Por ejemplo, Aristóteles compara el movimiento de los animales con artefactos mecánicos automáticos. En los animales, como en los autómatas, un ímpetu inicial conduce al movimiento. Además, después de ese ímpetu inicial, ambos pueden continuar moviéndose gracias su organización interna.

En la segunda mitad del siglo diecisiete, la filosofía mecanicista experimental se convirtió en el enfoque dominante en la filosofía natural. Estaba influenciada por las artes mecánicas y las ciencias matemáticas contemporáneas, y se oponía a la ciencia aristotélica y al vitalismo. La filosofía mecanicista moderna, en tanto que programa general, fue introducida por Robert Boyle (Roux, 2018).[2] Esta filosofía involucra una visión reduccionista según la cual la materia pasiva y el movimiento son los constituyentes últimos del mundo. Solo existe una materia universal, la cual es extendida, divisible e impenetrable. El movimiento, el cual es siempre local, divide la materia en partes de diferentes tamaños y formas. La variedad de fenómenos en el mundo es resultado de las diversas formas, tamaños, movimientos y relaciones de las partes de la materia. Además de una posición metafísica, la filosofía mecanicista moderna es una tesis sobre la metodología científica (Nadler, 1998; Psillos & Ioannidis, 2019). Se considera que los fenómenos deben ser explicados en términos de materia y movimiento. En una explicación satisfactoria, el explanans especifica como cierta configuración de materia en movimiento, sujeta a leyes, da lugar al fenómeno de interés.

[2] Boyle introdujo el programa general de la filosofía mecanicista en el prefacio de *Some specimens of an attempt to make chymical experiments useful to illustrate the notions of the corpuscular philosophy* publicado en sus *Certain Physiological Essays* (1661). El término 'filosofía mecanicista' había sido utilizado previamente para caracterizar la filosofía de Descartes (Roux, 2018). Por ejemplo, en una carta enviada a Descartes en 1637, Libert Froidmont afirmó que su filosofía era demasiado tosca y mecanicista debido a la influencia de la física epicúrea en ella. Sin embargo, como Roux (2018) ha argumentado, esas apariciones del término no deben ser equiparadas con el establecimiento de la filosofía mecanicista como programa general. No proporcionan un marco dentro del cual diferentes propuestas sean posibles; exclusivamente caracterizan la filosofía cartesiana.

La filosofía mecanicista del siglo diecisiete, a diferencia de la filosofía natural aristotélica y el vitalismo, rechaza establecer una distinción fuerte entre los seres artificiales y los seres naturales (Garber, 2002; Hattab, 2011). Se considera que, aunque difieren en su causa, su naturaleza es similar. Los seres naturales son simplemente máquinas más complejas. No hay diferencias fundamentales entre el comportamiento de los fenómenos naturales y artificiales. Y, consecuentemente, ambos deben ser explicados en términos de materia y movimiento. En este sentido, por ejemplo, se desarrollan explicaciones mecanicistas del movimiento autónomo de los seres vivos (Des Chene, 2005). Además, los artefactos (p. ej. simios animados) son frecuentemente utilizados para explicar fenómenos naturales. Los mecanismos que gobiernan los fenómenos naturales raramente son visibles, pero los mecanismos internos de los artefactos son normalmente más grandes. Así que los artefactos permiten a los filósofos mecanicistas ilustrar esos mecanismos invisibles. Tal y como de Solla Price argumenta, su existencia misma "offered a tangible proof, more impressive than any theory, that the natural universe of physics and biology was susceptible to mechanistic explanation" (1964, p. 9).

Boyle planteó una caracterización general y amplia de la filosofía mecanicista. Dentro del marco mecanicista, hay lugar para diferentes propuestas (Boas, 1952; Psillos, 2011). Los mecanicistas pueden tener ideas distintas respecto a la estructura de la materia, las propiedades fundamentales de la materia, la realidad del vacío, etc. Suele señalarse a Descartes como ejemplo paradigmático de mecanicista (Roux, 2004). Descartes mantiene que la materia, la cual es infinitamente divisible, y el movimiento son los constituyentes últimos del mundo. Considera que las leyes del movimiento son capaces de explicar todos los fenómenos del mundo. En este sentido, afirma que la física no es nada más que mecánica —el estudio del movimiento—. Además, sus explicaciones frecuentemente refieren a artefactos (p. ej. autómatas). Sin embargo, otros filósofos como Thomas Hobbes, Pierre Gassendi o John Locke, que están en desacuerdo con muchos aspectos del enfoque cartesiano, también serían considerados mecanicistas. De hecho, pronto la noción de filosofía mecanicista fue ampliada para incluir a todos aquellos que defendían la relevancia de las explicaciones mecanicistas, con independencia de si respaldaban la ontología mecanicista (Roux, 2018). En este sentido, la mayoría de las figuras relevantes de la ciencia y la filosofía del siglo diecisiete, tales como Isaac Newton y Gottfried Wilhelm Leibniz, pueden ser caracterizadas como mecanicistas.

Los filósofos mecanicistas modernos reconocieron la influencia del atomismo antiguo (Buyse, 2013). La filosofía mecanicista del siglo diecisiete es también una visión del mundo reduccionista, en la cual la materia homogénea es considerada uno de sus principales constituyentes. Además, mantiene que los fenómenos deben ser explicados en términos de materia, movimiento, posición y otras cualidades mecánicas de los cuerpos. Sin embargo, hay diferencias relevantes entre el atomismo antiguo y la filosofía mecanicista moderna (Bennett, 1986). Por un lado, muchos mecanicistas rechazan tesis centrales del atomismo. Por ejemplo, Descartes considera que no hay vacío y que la materia es infinitamente divisible. Y, por otro lado, el enfoque moderno incluye muchos aspectos ausentes en la filosofía antigua, tales como el método experimental, el uso de instrumentos matemáticos y el desarrollo de modelos mecanicistas.

En los siglos posteriores, el enfoque mecanicista continuó siendo una de las principales corrientes dentro de la ciencia. La investigación científica a menudo estaba relacionada con el desarrollo de modelos mecanicistas que daban cuenta de fenómenos observables. Ejemplos representativos de esos modelos son el modelo cinético de los gases de James Clerk Maxwell y el modelo hexagonal de la molécula de benceno de August Kekulé. Sin embargo, no había una interpretación estándar de la filosofía mecanicista compartida por todos los científicos. La interpretación podía variar dependiendo del periodo, la región e incluso la institución (Smith, 1976; Baracca, 2005). La pluralidad de enfoques mecanicistas iba desde los que defendían las explicaciones en términos de interacciones entre entidades elementales no observables, a los que se centraban en desarrollar sistemas de leyes en base a los principios fundamentales de la dinámica.

A pesar de su prevalencia, el enfoque mecanicista fue objeto de críticas. Estas críticas fueron especialmente severas en el campo de la biología (Allen, 2005, 2018). Varios autores afirmaron que la filosofía mecanicista era un modo demasiado simplista de considerar los organismos vivos y plantearon propuestas alternativas. Frecuentemente, estas propuestas alternativas se basaban en la idea de que los organismos vivos tienen propiedades emergentes y han de ser estudiados en su conjunto. Se consideraba que no pueden ser reducidos a sus componentes. Entre 1700 y 1850, la mayoría de los filósofos y científicos críticos con el enfoque mecanicista, como Xavier Bichat y Johannes Peter Müller, defendían alguna forma de *vitalismo*. Ellos sostenían que cierta fuerza inmaterial, la cual no tiene equivalente en el mundo inanimado, caracteriza a los organismos vivos. No obstante, a finales del siglo diecinueve y principios del siglo veinte, varias alternativas materialistas al enfoque mecanicista fueron defendidas (p. ej. materialismo dialéctico). Los materialistas holistas consideraban que, para entender los sistemas complejos, es necesario ir más allá de las partes individuales y abordarlos como un todo. Pero ellos rechazaban cualquier fuerza que no pudiera ser entendida en términos de la física y la química conocidas. Los materialistas holistas querían dar cuenta de los sistemas complejos en términos puramente fisicoquímicos.

Durante la mayor parte del siglo veinte, la filosofía de la ciencia estuvo dominada por el *empirismo lógico* y el modelo explicativo de cobertura legal. De acuerdo con este modelo, un fenómeno es explicado al ser subsumido bajo una ley (Hempel, 1965). Las explicaciones son caracterizadas como argumentos donde las premisas, que incluyen esencialmente al menos una ley, implican (con certeza deductiva o con alta probabilidad inductiva) la conclusión, la cual describe el fenómeno explanandum. Sin embargo, desde principios de la década de 1960, fueron formulados numerosos contraejemplos que mostraban que la subsunción bajo leyes es innecesaria e insuficiente para explicar un fenómeno (véase Salmon, 1989). En este contexto, algunos filósofos como Peter Railton y Wesley C. Salmon desarrollaron propuestas mecanicistas como alternativa al erosionado modelo de cobertura legal.

Railton (1978) criticó la concepción del modelo de cobertura legal de las explicaciones probabilísticas de fenómenos particulares —el modelo estadístico-inductivo—. De acuerdo con este modelo, una explicación probabilística es un argumento en el cual las premisas, que contienen esencialmente al menos una ley estadística, implican con alta probabilidad inductiva la conclusión, que describe el fenómeno explanandum. Railton cuestiona que las explicaciones probabilísticas sean argumentos y que deban hacer muy probable el explanandum. Considera que entendemos los fenómenos improbables igual de bien que los fenómenos altamente probables. Railton argumenta que la explicación probabilística no consiste en hacer a los fenómenos explanantia nómicamente esperables, si no en entender los mecanismos estocásticos que les dan lugar. En consecuencia, afirma que la explicación probabilística de un fenómeno debe "give an account of the chance mechanism(s) responsible for it" (Railton, 1978, p. 206). Él entiende un mecanismo como "a more or less complete filling-in of the links in the causal chains" (Railton, 1978, pp. 208-209).

En su influyente *Scientific Explanation and the Causal Structure of the World* (1984), Salmon argumenta que "[t]o understand the world and what goes on in it, we must expose its inner workings. To the extent that causal mechanisms operate, they explain how the world works" (1984, p. 133). Él considera que explicar un fenómeno es mostrar como encaja en la estructura causal del mundo. Un fenómeno es satisfactoriamente explicado cuando se identifican (parte de) los procesos y las interacciones causales que le dan lugar. Salmon caracteriza los procesos y las interacciones causales en términos del criterio contrafáctico de 'transmitir una marca'. Un proceso causal es definido como un proceso capaz de transmitir una marca (una modificación en su estructura), esté o no realmente transmitiéndola (Salmon, 1984, p. 147). Un ejemplo paradigmático de proceso causal es el movimiento de una partícula libre. Las interacciones causales son intersecciones de dos procesos causales en las cuales ambos son modificados de forma persistente de un modo que no hubiera ocurrido sin dicha intersección (Salmon, 1984, p. 171). Una colisión de dos partículas, por ejemplo, constituiría una interacción causal. Sin embargo, se criticó que estas definiciones de proceso e interacción causal admiten contraejemplos y no son una guía fiable para descubrir la estructura causal del mundo (Kitcher, 1989; Dowe, 1992). En respuesta a esas críticas, siguiendo a Phil Dowe (1992), Salmon redefinió esos conceptos en términos de cantidades conservadas. Un proceso causal es caracterizado como "a world-line of an object that transmits a nonzero amount of an invariant quantity at each moment of its history (each spacetime point of its trajectory)" (Salmon, 1994, p. 308). Una interacción causal ocurre cuando líneas de mundo intersecan y una cantidad conservada es intercambiada (Salmon, 1994, p. 303).

La propuesta de Salmon, igual que la filosofía mecanicista del siglo diecisiete, es ontológicamente austera (Hitchcock, 1995). La estructura causal del mundo es reducida a procesos e interacciones físicas. Sin embargo, Salmon considera que el modelo mecánico causal puede dar cuenta de la mayoría de las explicaciones en ciencia. En este sentido, afirma: "I hope that the causal theory of scientific explanation outlined above in this book is reasonably adequate for the characterization of explanation in most scientific contexts—in the physical, biological and social sciences—as long as we do not become involved in quantum mechanics" (Salmon, 1984, p. 278). Ciertamente, este modelo se ajusta a los sistemas físicos más simples, cuyo comportamiento está gobernado por los principios de la mecánica clásica y el electromagnetismo. Sin embargo, como James Woodward (1989) pronto señaló, la propuesta de Salmon difícilmente puede dar cuenta de la explicación en campos como la biología, la psicología y la economía. En esos campos, a menudo se trata como similares a sistemas que difieren significativamente en su estructura física subyacente. Por ejemplo, considere las situaciones adaptativas. Cuando las presiones selectivas presentes son análogas, dos situaciones adaptativas pueden ser consideradas similares, aunque los mecanismos subyacentes sean bastante diferentes. Esta idea se halla a la base de los modelos desarrollados en la teoría evolutiva de juegos.

3. La nueva filosofía mecanicista

La *nueva filosofía mecanicista* surgió entre finales de la década de 1980 y principios de la década de 1990. Este surgimiento estuvo relacionado con la publicación de libros como *Nuts and Bolts for Social Sciences* (1989) de Jon Elster and *Discovering Complexity: Decomposition and Localization as Strategies in Scientific Research* (1993) de William Bechtel y Robert Richardson. El nuevo enfoque mecanicista se opone al empirismo lógico y a la concepción de la ciencia en términos de leyes y teorías. Se considera que la investigación científica no debería entenderse como una búsqueda de leyes universales, sino como una búsqueda de mecanismos. Esos mecanismos son representados por modelos mecanicistas, los cuales juegan el papel de las teorías. Los científicos usan los modelos mecanicistas para representar, explicar, predecir e intervenir en el mundo.

Dentro de la nueva filosofía mecanicista, pueden distinguirse dos líneas de trabajo: el ‘nuevo mecanismo’ y el ‘mecanismo social’ (Glennan & Illari, 2018). El nuevo mecanismo, que enlaza con el trabajo seminal de Bechtel y Richardson, ha sido desarrollado principalmente por filósofos de la ciencia interesados en las ciencias de la vida (biología, neurociencia, medicina, etc.). Algunas contribuciones tempranas importantes, las cuales lo definieron parcialmente, son “Mechanisms and the Nature of Causation” (1996) de Stuart Glennan y “Thinking about Mechanisms” (2000) de Peter Machamer, Lindley Darden y Carl F. Craver (en adelante MDC). Estos artículos caracterizan los mecanismos y, tomándolos como referencia, abordan varios problemas filosóficos como la causalidad o la explicación científica. El mecanismo social, el cual enlaza con el influyente trabajo de Elster, se centra en las ciencias sociales, especialmente en la sociología y la economía. Ha sido desarrollado por científicos sociales y está íntimamente relacionado con la sociología analítica. La sociología analítica es un movimiento metodológico en sociología que reivindica la relevancia de los mecanismos. Sus principios fundamentales han sido expuestos en libros como *Social Mechanisms: An Analytical Approach to Social Theory* (1998) editado por Peter Hedström y Richard Swedberg y *Dissecting the Social: On the Principles of Analytical Sociology* (2005) de Hedström. Una de sus ideas centrales, la cual es compartida por todos los sociólogos analíticos, es que el principal objetivo de la sociología debería ser explicar macrofenómenos sociales en base a los mecanismos responsables de ellos.

El nuevo mecanismo y el mecanismo social surgieron independientemente y, durante varios años, las discusiones en filosofía y en ciencias sociales se han desarrollado por separado. Sin embargo, la interacción entre ambas líneas de trabajo ha ido creciendo progresivamente. Por ejemplo, nociones de mecanismo desarrolladas por defensores del nuevo mecanicismo han sido adoptadas por científicos sociales asociados al mecanismo social (véase, por ejemplo, Hedström, 2005, p. 25).

Al igual que enfoques mecanicistas previos, tales como la filosofía mecanicista moderna o la propuesta de Salmon, la nueva filosofía mecanicista es tanto una filosofía natural como una filosofía de la ciencia (Glennan, 2016, 2017). Por un lado, es una investigación filosófica sobre la constitución y organización del mundo. Los nuevos mecanicistas consideran que los mecanismos son uno de los principales constituyentes del mundo y que todos o la mayoría de los fenómenos del mundo dependen de ellos. Ellos investigan la naturaleza de los mecanismos en tanto que categoría ontológica y como se relacionan con otras categorías ontológicas como las causas, las propiedades y los niveles de organización. Por otro lado, la nueva filosofía mecanicista es una investigación filosófica sobre la ciencia. Se considera que los mecanismos tienen un rol central en la empresa científica. Los nuevos mecanicistas estudian el descubrimiento de mecanismos, su representación por medio de modelos y su uso para explicar, predecir y controlar fenómenos. Es importante señalar que no todos los mecanicistas conceden la misma importancia a estos proyectos y están igualmente implicados en ambos. De hecho, algunos de ellos se centran en un proyecto y prácticamente ignoran el otro. Por ejemplo, considere a Gillies (2017, 2018), a quien he hecho referencia en la sección 1. Él analiza cuidadosamente como la evidencia de mecanismos puede contribuir a las inferencias causales y a la extrapolación causal, pero presta poca atención a los mecanismos en tanto que categoría ontológica.

Sin embargo, a diferencia de enfoques mecanicistas previos, la nueva filosofía mecanicista se caracteriza por un énfasis generalizado en la práctica científica real (Machamer et al., 2000; Glennan, 2017; Psillos & Ioannidis, 2019). El objeto de interés primero de los nuevos mecanicistas es el mecanismo en tanto que concepto-en-uso en la ciencia, no en tanto que categoría metafísica abstracta. Ellos están interesados en qué son los mecanismos y para qué son (o podrían ser) buenos en la ciencia. Los nuevos mecanicistas se centran en la práctica científica y la toman como la principal referencia para abordar tanto las cuestiones metodológicas como las cuestiones ontológicas relacionadas con los mecanismos. Se entiende que las consideraciones ontológicas sobre los mecanismos en tanto que constituyentes del mundo no pueden pasar por alto el rol de los mecanismos en la ciencia y las ideas de los científicos sobre ellos (Kaiser, 2018). Por ejemplo, el debate sobre qué tipo componentes constituyen los mecanismos y cuál es la relación entre ellos —¿es un tipo más fundamental que el resto o están ontológicamente a la par?— está guiado por el criterio de adecuación descriptiva (véase, por ejemplo, Machamer et al., 2000). De acuerdo con este criterio, una propuesta satisfactoria ha de ajustarse a los ejemplos paradigmáticos de mecanismo estudiados por los científicos.

La nueva filosofía mecanicista, igual que la filosofía mecanicista del siglo diecisiete, no es un movimiento completamente homogéneo. Los nuevos mecanicistas no tienen ideas e intereses idénticos. La nueva filosofía mecanicista es un marco dentro del cual distintas propuestas, las cuales pueden incluso entrar en conflicto, son defendidas. De hecho, aunque los nuevos mecanicistas están de acuerdo en la relevancia de los mecanismos, discrepan respecto a su definición. Dentro del nuevo marco mecanicista, ha habido diferentes intentos de ofrecer una caracterización satisfactoria de los mecanismos (Mahoney, 2001; Hedström & Ylikoski, 2010). Éstas son las definiciones más citadas:

> Mechanisms are entities and activities organized such that they are productive of regular changes from start or set-up to finish or termination conditions. (Machamer et al., 2000, p. 3)
>
> A mechanism for a behavior is a complex system that produces that behavior by the interaction of a number of parts, where the interaction between parts can be characterized by direct, invariant, change-relating generalizations. (Glennan, 2002, p. S344)
>
> A mechanism is a structure performing a function in virtue of its component parts, component operations, and their organization. The orchestrated functioning of the mechanism is responsible for one or more phenomena. (Bechtel & Abrahamsen, 2005, p. 423)
>
> A mechanism for a phenomenon consists of entities and activities organized in such a way that they are responsible for the phenomenon. (Illari & Williamson, 2012, p. 120)

Sin embargo, a pesar de los desacuerdos entre los nuevos mecanicistas, algunas ideas generales son compartidas por la mayoría de ellos. En primer lugar, los mecanismos son parte del mundo real (Glennan, 2016, 2017; Glennan & Illari, 2018). Son concebidos como cosas particulares ubicadas en cierto punto del espacio y el tiempo. Los nuevos mecanicistas siempre diferencian entre un mecanismo, el cual es algo real, y un modelo suyo, el cual es a menudo un fragmento de razonamiento científico. Aunque hay discrepancias respecto a la estabilidad atribuida a los mecanismos. Algunos nuevos mecanicistas consideran que todos los mecanismos son sistemas complejos, es decir, configuraciones estables de varios componentes. (p. ej. Bechtel & Abrahamsen, 2005). Pero otros argumentan que los procesos causales, que son menos estables y no pueden ser considerados objetos, también pueden constituir mecanismos (p. ej. Illari & Williamson, 2012). En segundo lugar, los mecanismos están compuestos por entidades (o partes) y actividades (o interacciones) (Machamer et al., 2000; Illari & Williamson, 2012; Glennan, 2017). Las entidades son cosas que toman parte en actividades. Normalmente están localizadas espaciotemporalmente, estructuradas y orientadas. Ejemplos de entidades son las neuronas, las empresas y los órganos. Las actividades son sucesos productivos. Tienen orden temporal, ritmo y duración. Ejemplos de actividades son transportar, irradiar y comprar. Las entidades y actividades de un mecanismo están organizadas. Esa organización puede tener muchos aspectos diferentes, tales como temporal, espacial, causal, etc. En tercer lugar, un mecanismo es siempre un mecanismo para un fenómeno (Glennan, 1996, 2017; Hedström & Ylikoski, 2010). Por ejemplo, el sistema digestivo es el mecanismo que sustenta el fenómeno de la digestión. La identificación y delimitación de un mecanismo dependen del fenómeno del cual es responsable. Un mecanismo no puede siquiera ser identificado sin indicar qué es lo que hace. Y, en cuarto lugar, hay diferencias significativas entre los mecanismos y las máquinas (Glennan, 2017; Craver & Tabery, 2019). Aunque las máquinas hechas por el hombre (p. ej. relojes) a menudo pueden considerarse mecanismos, la mayoría de los mecanismos estudiados en la ciencia no son máquinas. Su comportamiento no puede ser reducido a ciertas fuerzas mecánicas fundamentales. No obstante, la metáfora de la máquina es aún considerada una herramienta útil para ilustrar el comportamiento de los sistemas naturales complejos.

Otra importante idea compartida por todos los nuevos mecanicistas es que los mecanismos están anidados y forman una jerarquía (Machamer et al., 2000; Glennan, 2017). Los mecanismos pueden descomponerse en mecanismos de nivel inferior. Un mecanismo está compuesto de entidades y actividades organizadas, las cuales son responsables de sus propiedades y comportamiento. Y esos componentes son habitualmente ellos mismos mecanismos, cuyas propiedades y comportamiento también dependen de sus propios componentes. Por ejemplo, los componentes del sistema nervioso (celebro, médula espinal, nervios, transmisión de señales, etc.), los cuales son responsables de sus propiedades y comportamiento, son ellos mismos mecanismos. Sin embargo, a diferencia de mecanicistas previos, los nuevos mecanicistas no defienden una concepción reduccionista del mundo (Andersen, 2014). Rechazan que sea posible reducir mecanismos de nivel superior a mecanismos de nivel inferior. Aunque hay relaciones ontológicas y explicativas entre niveles superiores e inferiores, esto no conlleva la eliminación de los niveles superiores ni su reducción a los niveles inferiores. Los nuevos mecanicistas se toman enserio la existencia de las cosas complejas. Sostienen que nuevos y diferentes tipos de entidades y actividades surgen en los diferentes niveles de organización. Además, los nuevos mecanicistas consideran que las explicaciones de nivel alto pueden ser perfectamente legítimas (Machamer et al., 2000); los científicos no tienen que apelar siempre a un nivel fundamental predeterminado (p. ej. la física fundamental). Qué se considera como componentes básicos depende del dominio y la motivación.

A pesar de su novedad y originalidad, la nueva filosofía mecanicista entronca con la tradición mecanicista y hereda de ella algunas de sus ideas centrales. En este sentido, algunos aspectos importantes de la nueva filosofía mecanicista fueron anticipados por Salmon (1984, 1994, 1998). De hecho, respecto a la relación entre Salmon y los mecanicistas contemporáneos, Campaner ha afirmado que "his work already presents many interesting hints at what are now regarded as the crucial steps *forward* in dealing with mechanistic causation" (2013, p. 82). Salmon ya puso el énfasis en las nociones de producción e interacción, las cuales tienen un rol central en el nuevo enfoque mecanicista. Los nuevos mecanicistas subrayan la naturaleza activa de los mecanismos (Machamer, 2004; Glennan, 2017). Dan cuenta de los mecanismos como entidades que toman parte en actividades o interacciones productivas. Además, en ambos casos la *continuidad* productiva es crucial. Tal y como se ha señalado, Salmon (1984, 1994) afirma que la continuidad espaciotemporal caracteriza a los procesos causales y los distingue de los pseudoprocesos. Los nuevos mecanicistas consideran que la continuidad productiva entre estadios hace inteligible su relación y es responsable de la regularidad de los mecanismos (Machamer et al., 2000). Otro aspecto de la nueva filosofía mecanicista que ya está presente en la propuesta de Salmon es el rol central de los contrafácticos activos o experimentales. En la versión original de su modelo mecánico causal, Salmon (1984) apela a contrafácticos experimentales para distinguir los procesos causales de los no causales. Y, en la nueva filosofía mecanicista, se considera que los contrafácticos intervencionistas son cruciales para identificar las variables relevantes y determinar los componentes de los mecanismos (Glennan, 2002; Craver, 2007).

Por lo que respecta a la explicación científica, Salmon (1984) también introduce muchas ideas posteriormente defendidas por la nueva filosofía mecanicista.[3] Él afirma que, para desarrollar una concepción adecuada de la explicación científica, la práctica científica ha de ser tenida en cuenta y que en la mayoría de los campos científicos las explicaciones son mecanicistas. Salmon (1984, p. 175) también subraya las aspectos etiológicos y constitutivos de las explicaciones basadas en mecanismos. Para explicar por qué un evento E ocurrió, se han de identificar los procesos e interacciones causales relevantes en el pasado de E. Sin embargo, si uno quiere explicar por qué E posee ciertas características, ha de revelar los mecanismos causales internos que dan cuenta de la naturaleza de E. Otro aspecto anticipado por Salmon es reconocer la relevancia de la función y el contexto en los enfoques mecanicistas. Él (1998) argumenta que las explicaciones funcionales son explicaciones legítimas y constituyen un subconjunto de las explicaciones mecanicistas. Los nuevos mecanicistas, respecto al análisis funcional, afirman que puede ser crucial para delimitar los mecanismos y elaborar modelos mecanicistas explicativos (Bechtel & Abrahamsen, 2005). Por lo que refiere al contexto, Salmon (1984, 1989) considera que éste tiene un rol central en el análisis de los mecanismos. Argumenta que, aunque a los fenómenos subyace una estructura causal objetiva, los aspectos de la estructura causal que seleccionamos y el nivel de descripción que escogemos dependen del contexto. De forma similar, los nuevos mecanicistas afirman que el nivel de detalle adecuado en los modelos mecanicistas depende del contexto (Craver, 2001; Bogen, 2005).

Sin embargo, es importante señalar que hay diferencias significativas entre el modelo mecánico causal de Salmon y la nueva filosofía mecanicista. Aunque Salmon también está preocupado por el rol de los mecanismos en la ciencia, su objeto de interés primero son categorías metafísicas (Psillos & Ioannidis, 2019). A diferencia del nuevo enfoque mecanicista, él empieza discutiendo los procesos y las interacciones causales como categorías metafísicas abstractas. Y, posteriormente, tomando ese análisis como marco de referencia, aborda las cuestiones metodológicas. Ambos enfoques mecanicistas también difieren en los campos científicos que toman como referencia. La propuesta de Salmon se centra en la física, en particular en un subcampo de ella: la mecánica clásica. Sin embargo, los nuevos mecanicistas consideran diversos campos, como la biología, la neurociencia y la sociología. También hay diferencias importantes respecto a la noción

[3] La concepción de la explicación científica de la nueva filosofía mecanicista y el rol central que en ella ocupan estas ideas serán discutidos en la sección 4.

misma de mecanismo (Glennan, 2002). Primero, mientras que los mecanicistas contemporáneos discuten cuidadosamente la caracterización de los mecanismos y su rol en la ciencia actual, Salmon presta poca atención a esas cuestiones. Él no proporciona una definición explícita de mecanismo, ni tiene en cuenta los diversos roles que juegan en la ciencia. Segundo, en la propuesta de Salmon, se considera que todos los mecanismos consisten en secuencias de procesos e interacciones causales (p. ej. una secuencia de colisiones entre partículas). Sin embargo, los nuevos mecanicistas mantienen que los mecanismos pueden ser configuraciones estables de entidades y actividades (p. ej. una célula).[4] Finalmente, aunque las interacciones causales son importantes en ambas propuestas, éstas no son entidades del mismo modo. En el nuevo enfoque mecanicista, las interacciones son a menudo caracterizadas en términos de generalizaciones invariantes de cambio relativo (Woodward, 2003).

4. La nueva concepción mecanicista de la explicación científica

De acuerdo con la nueva filosofía mecanicista, el papel de los mecanismos en la ciencia está a menudo asociado al objetivo científico de explicar. Al igual que mecanicistas previos, los nuevos mecanicistas defienden una concepción mecanicista de la explicación. Ellos consideran que un fenómeno se explica por medio de especificar el mecanismo responsable de él. En este sentido, MDC afirman: "To give a description of a mechanism for a phenomenon is to explain that phenomenon" (Machamer et al., 2000, p. 3). La concepción mecanicista de la explicación se opone al modelo de cobertura legal y a los acercamientos estadísticos a la explicación científica (Bechtel & Abrahamsen, 2005; Hedström, 2005). Las explicaciones nomológicas y las estadísticas son 'explicaciones de caja negra'. Conectan las condiciones iniciales con el resultado final por medio de leyes universales o generalizaciones estadísticas. Sin embargo, los procesos a través de los cuales el explanans y el explanandum están realmente conectados no son abordados por ellas. Se considera que esa conexión carece de estructura o que su estructura es irrelevante. Por el contrario, las explicaciones mecanicistas son explicaciones-como. Ellas especifican "how some phenomenon comes about" (Glennan, 2017, p. 228). Las explicaciones mecanicistas abren la caja negra entre explanans y explanandum, y detallan los procesos que dan lugar a este último. Un ejemplo paradigmático de explicación basada

[4] Aunque algunos nuevos mecanicistas están de acuerdo en que ciertos procesos causales pueden ser considerados mecanismos, ellos no sostienen que todos los mecanismos sean procesos causales. Como se ha señalado, reconocen que muchos mecanismos son sistemas complejos estables.

en mecanismos es la explicación que Salganik, Dodds y Watts ofrecen de la desigualdad de éxito en los mercados culturales (véase la sección 1). Los autores especifican las tuercas y los tornillos sociales del proceso causal a través del cual ese macrofenómeno social es producido. Detallan como la conducta (no independiente) de los consumidores individuales produce que los productos culturales exitosos sean varias veces más exitosos que la media.

Por lo que respecta a la relación entre los mecanismos y los fenómenos de interés, las explicaciones basadas en mecanismos pueden ser causales o constitutivas (Ylikoski, 2013). Tanto la causación como la constitución son relaciones de dependencia, pero hay diferencias metafísicas importantes entre ellas. La causación es habitualmente una relación entre eventos, requiere tiempo y es asimétrica respecto a la manipulación (se puede producir un cambio en el efecto manipulando la causa, pero no al revés). Por otro lado, la constitución es frecuentemente una relación entre propiedades, es sincrónica y es simétrica respecto a la manipulación (se puede producir un cambio en el todo manipulando una parte, y al revés). Dependiendo de la relación entre el mecanismo identificado y el fenómeno de interés, una explicación es o una explicación mecanicista causal o una explicación mecanicista constitutiva.

Entre los nuevos mecanicistas, no existe consenso en relación a la naturaleza de las explicaciones mecanicistas (Illari, 2013). Siguiendo a Salmon (1984), algunos nuevos mecanicistas consideran que las explicaciones mecanicistas son *ónticas*. Estos argumentan que las explicaciones basadas en mecanismos explican porque encajan el fenómeno explanandum en la estructura causal del mundo. Para estos autores, las explicaciones son porciones objetivas de la estructura causal del mundo. En este sentido, Craver afirma: "Objective explanations are not texts; they are full-bodied things" (2007, p. 27). Sin embargo, otros nuevos mecanicistas consideran que las explicaciones basadas en mecanismos son explicaciones *epistémicas*. Estos mantienen que "[e]xplanation is fundamentally an epistemics activity" (Bechtel, 2008) y que las explicaciones basadas en mecanismos explican porque aumentan nuestro entendimiento del mundo. Para los defensores de la concepción epistémica, las explicaciones mecanicistas no son porciones de la estructura causal del mundo, sino representaciones de esas porciones (p. ej. textos).

Las explicaciones mecanicistas son habitualmente representadas mediante modelos mecanicistas. Un modelo mecanicista consta de dos componentes: una descripción fenoménica y una descripción mecanicista (Glennan, 2017). La descripción fenoménica es un modelo del fenómeno de interés, mientras que la descripción mecanicista es un modelo del mecanismo responsable de ese fenómeno. En las explicaciones basadas en mecanismos, la descripción fenoménica está relacionada con el explanandum y la descripción mecanicista con el explanans. Sin embargo, no hay consenso sobre los detalles de esas relaciones. Para la concepción óntica de las explicaciones mecanicistas, la descripción fenoménica *representaría* el explanandum y la descripción mecanicista *representaría* el explanans. Sin embargo, para la concepción epistémica, la descripción fenoménica y la mecanicista *serían* ellas mismas el explanandum y el explanans respectivamente.

5. La voluntad de generalidad y la heterogeneidad de las áreas científicas

Un aspecto central de la nueva filosofía mecanicista que no ha sido abordado con anterioridad y merece atención es la *voluntad de generalidad*. Los nuevos mecanicistas consideran que los mecanismos son relevantes en la mayoría de las áreas científicas y tratan de plantear un enfoque mecanicista que las englobe a todas. La búsqueda de generalidad y amplia aplicabilidad se manifiesta en la mayoría de las propuestas desarrolladas en el marco de la nueva filosofía mecanicista. Cuando los nuevos mecanicistas abordan cuestiones como la explicación, la inferencia causal o el descubrimiento científico, tratan de dar una respuesta que se aplique a todos los campos de la ciencia donde los mecanismos son relevantes.

5.1. Nociones generales de mecanismo

Un aspecto de la nueva filosofía mecanicista, especialmente del nuevo mecanismo, que ilustra la voluntad de generalidad es la caracterización de los mecanismos. La búsqueda de generalidad está presente en la mayoría de las nociones de mecanismo actuales. Los nuevos mecanicistas consideran que una noción de mecanismo apropiada debería ser adecuada para la mayoría de las áreas donde los mecanismos son relevantes. Y, en consecuencia, tratan de desarrollaran una noción general de mecanismo que englobe los diversos tipos de mecanismo. Este aspecto del nuevo enfoque mecanicista es discutido en “The Search for Generality in the Notion of Mechanism” (anexo 1).

A pesar de que la búsqueda de generalidad es un rasgo común a las caracterizaciones de mecanismo actuales, no siempre es perseguido mediante la misma estrategia. Dentro de la nueva filosofía mecanicista, encontramos dos estrategias para desarrollar nociones generales de mecanismo: la estrategia de extrapolación y la estrategia a-través-de-las-ciencias. La *estrategia de extrapolación* consiste en desarrollar una noción de mecanismo tomando una o unas pocas áreas de la ciencia como referencia, y luego aplicar esa noción a muchas otras áreas. Esta estrategia va de un tipo particular de mecanismos a una noción general de mecanismo. MDC (2000), por ejemplo, adoptan la estrategia de extrapolación. Su noción de mecanismo fue desarrollada tomando como guía los mecanismos neurobiológicos y moleculares. Sin embargo, ellos consideran que esa noción se ajusta a muchas otras áreas: "We suspect that this analysis is applicable to many other sciences, and maybe even to cognitive or social mechanisms" (Machamer et al., 2000, p. 2). La estrategia de extrapolación también ha sido adoptada por otros autores como Glennan (1996, 2002) y Woodward (2002).

Por otro lado, la *estrategia a-través-de-las-ciencias* consiste en considerar los mecanismos de todas las ciencias y desarrollar una noción que incluya sus rasgos comunes. Esta estrategia va de todos los mecanismos a una noción general de mecanismo. La estrategia a-través-de-las-ciencias fue introducida por Illari y Williamson (2012). Su objetivo es considerar los mecanismos en general y proponer "a characterization that gives an understanding of what is common to mechanisms in *all* fields" (Illari & Williamson, 2012, p. 120). La estrategia a-través-de-las-ciencias ha sido recientemente adoptada por Glennan (2017). Ha abandonado su noción de mecanismo previa (véase la sección 3), y propone una caracterización mínima, la cual trata de incluir aquello que es común a todos los mecanismos.

La búsqueda de generalidad es muy razonable. Hay muchos tipos de mecanismos en la ciencia (p. ej. mecanismos sociales, mecanismos neuronales, mecanismos evolutivos, etc.). Una noción que pudiera dar cuenta de todos ellos sería de utilidad tanto para la investigación científica como para la comprensión filosófica. Facilitaría la colaboración entre diferentes áreas de la ciencia donde los mecanismos son relevantes. Además, una noción general de mecanismo ayudaría a abordar diferentes cuestiones filosóficas (p. ej. la explicación científica). Sin embargo, las dos estrategias sugeridas para alcanzar la generalidad encuentran importantes dificultades.

El principal problema de la estrategia de extrapolación es que las nociones de mecanismo desarrolladas tomando cierto tipo de mecanismos como referencia no se ajustan a muchos otros tipos. Para analizar las dificultades de la estrategia de extrapolación, tomo como referencia la propuesta de MDC (véase la sección 3). Tal y como se ha señalado, MDC consideran que su noción de mecanismo podría aplicarse en la mayoría de las áreas científicas. Sin embargo, es dudoso que sea así. Por ejemplo, la noción de MDC es incapaz de dar cuenta de los mecanismos económicos. Un ejemplo bien conocido de mecanismo económico son los mecanismos de transmisión monetaria. Un mecanismo de transmisión monetaria es un mecanismo responsable de la influencia de un banco central en la producción, el empleo, los precios y la inflación de un país o una unión política y económica (Samuelson & Nordhaus, 2010, p. 484). Podría parecer que la noción de MDC se ajusta a ellos, pero difícilmente es ese el caso.

MDC afirman que los mecanismos son regulares. Lane DesAutels (2016) ha mostrado que para satisfacer su requisito de regularidad un mecanismo ha de ser regular respecto al proceso y no verse afectado por fuentes internas de irregularidad. Sin embargo, los mecanismos de transmisión monetaria no son regulares respecto al proceso y se ven afectados por fuentes internas de irregularidad. Las entidades componentes de los mecanismos de transmisión monetaria (p. ej. los bancos centrales) no se comportan siempre de la misma manera. Además, los cambios en sus componentes son a menudo resultado de fuentes internas; por ejemplo, cambios en los órganos de decisión.

Otro aspecto de la propuesta de MDC que no se ajusta a los mecanismos de transmisión monetaria es el establecimiento de los límites de los mecanismos. Craver (2007) mantiene que el mecanismo de cierto fenómeno está compuesto por las entidades, actividades y rasgos organizacionales que son parte del sistema cuyo comportamiento constituye ese fenómeno y son relevantes para el fenómeno. Sin embargo, esa idea no se ajusta a los mecanismos de transmisión monetaria. Un mecanismo de transmisión monetaria es un mecanismo de cierto fenómeno, a saber, la influencia de un banco central en la producción, el empleo, los precios y la inflación. Pero no está compuesto por todas las entidades, actividades y aspectos organizacionales que son parte del sistema (p. ej. un país) cuyo comportamiento es el fenómeno de interés y son relevantes para ese fenómeno.

Por lo que respecta a la estrategia a-través-de-las-ciencias, el principal problema es que las nociones de mecanismo son vacuas y demasiado amplias. Para discutir las dificultades de la estrategia a-través-de-las-ciencias, tomo como referencia la propuesta de Illari y Williamson (véase la sección 3). La definición de mecanismo de Illari y Williamson descansa sobre los conceptos de entidad, actividad, organización y ser responsable de. Sin embargo, no ofrecen una caracterización adecuada de esos conceptos. No ofrecen ni una definición de ellos, ni un conjunto de condiciones necesarias o suficientes para ser cierto tipo de componente. Consecuentemente, la noción se torna vacua. Se aumenta su alcance a costa de disminuir su precisión. Además, la noción de Illari y Williamson es demasiado amplia. Aunque ellos consideran que su caracterización “is not so broad that it captures non-mechanisms” (Illari & Williamson, 2012, p. 129), ésta subsume cosas que difícilmente aceptaríamos como mecanismos. Por ejemplo, su noción admitiría como mecanismo a un grupo de bebes durmiendo la siesta.

El objetivo de Illari y Williamson es desarrollar una noción amplia de mecanismo que englobe a los mecanismos de todas las áreas. Sin embargo, a pesar de que parece que están dispuestos a disminuir la precisión de la noción de mecanismo para aumentar su alcance, su noción no permite dar cuenta de varios tipos de mecanismos. No evita el problema de la estrategia de extrapolación. Illari y Williamson, como MDC, afirman que el mecanismo de un fenómeno está compuesto por los componentes (entidades, actividades y rasgos organizacionales) que son relevantes para tal fenómeno. Sin embargo, tal y como se ha señalado, esta idea no se ajusta a los límites de los mecanismos económicos.

Las dificultades enfrentadas por la búsqueda de generalidad en la noción de mecanismo socaban un frecuente argumento en favor de la nueva concepción mecanicista de la explicación científica.[5] A menudo se afirma que la nueva concepción mecanicista de la explicación es capaz de englobar las explicaciones de muchas áreas de la ciencia (Hedström & Ylikoski, 2011). Dado que los mecanismos son relevantes en muchas áreas, los nuevos mecanicistas argumentan que el enfoque mecanicista podría ser adoptado en la mayoría de los campos científicos. Esta idea también favorece el enfoque mecanicista frente a otras alternativas. Por ejemplo, un conocido problema del modelo de cobertura legal es que existen áreas de la ciencia donde solo se conocen unas pocas leyes, como la biología evolutiva (véase Scriven, 1959; Beatty, 1995). Una concepción nomológica de la explicación difícilmente podría ser adoptada en esos campos. Sin embargo, a menudo se conocen muchos mecanismos en esas áreas en las que no hay leyes disponibles. La propuesta mecanicista sería más ampliamente aplicable que las alternativas nomológicas.

Este habitual argumento descansa sobre la asunción de que la misma noción de mecanismo existe en todos los campos en que los mecanismos son relevantes. Se considera que el enfoque mecanicista podría ofrecer una concepción unificadora de la explicación porque en muchos campos los fenómenos podrían ser explicados por medio de mecanismos. Pero sería una propuesta unificadora solo si los mecanismos son similarmente entendidos en todas las áreas. Si las diversas áreas entendieran los

[5] La falta de éxito de la búsqueda de generalidad también socaba otras propuestas relacionadas con la nueva filosofía mecanicista. Por ejemplo, cuestiona la idea de que el nuevo enfoque mecanicista pueda proporcionar un marco para la integración de diferentes campos. Véase Pérez-González (en prensa) para el análisis de un caso partícular; la integración basada en mecanismos de la neurociencia y la ciencia social.

mecanismos de modos muy diferentes, la concepción mecanicista difícilmente sería unificadora. Sin embargo, esa asunción fundamental —los mecanismos son similarmente entendidos en todas las áreas— es cuestionada por las dificultades a las que se enfrenta la búsqueda de generalidad. La búsqueda de generalidad constituye el verdadero intento de identificar esa idea compartida de mecanismo. Los nuevos mecanicistas tratan de proponer una noción de mecanismo que se ajuste a la mayoría de las áreas en que los mecanismos son relevantes. Sin embargo, tal y como se ha argumentado, todas las estrategias para alcanzar la generalidad encuentran importantes dificultades. Esto significa que la asunción de que la misma noción de mecanismo es compartida por todos los campos no está justificada y requiere un mayor apoyo. No solo es que no se conozca tal noción, sino que muchos intentos de alcanzarla han fracasado.

5.2. Enfoques mecanicistas en biología evolutiva

Un campo de la ciencia donde el enfoque mecanicista y la aplicación de las nociones generales de mecanismo son especialmente controvertidos es la biología evolutiva. Los biólogos evolutivos a veces hablan de las causas evolutivas como mecanismos. Por ejemplo, se dice que la selección natural "is a powerful mechanism of evolution" (Herron & Freeman, 2014, p. 227) y que ella "is an effective mechanism for producing adaptation" (Bell, 2008, p. 499). Siguiendo este uso, algunos nuevos mecanicistas han tratado de desarrollar una concepción mecanicista de las causas evolutivas. En "Evolutionary causes as mechanisms: a critical analysis" (anexo 2), Victor J. Luque y yo analizamos los actuales acercamientos mecanicistas a la evolución causal, los cuales se centran principalmente en la selección natural, y exploramos su validez para dar cuenta de las causas evolutivas. Identificamos tres tipos diferentes de enfoques: la visión estocástica, la visión funcional y la visión minimalista. Los dos primeros están relacionados con la estrategia de extrapolación, mientras que el último ejemplifica la estrategia a-través-de-las-ciencias.

La *visión estocástica* se basa en la idea de que, dado que la selección natural es estocástica, sería posible dar cuenta de ella por medio de una versión estocástica de las actuales nociones de mecanismo. Se considera que rebajando la exigencia de regularidad es posible entender la selección natural como un mecanismo en el sentido planteado por MDC (2000) y Glennan (2002). El principal defensor de la visión estocástica es Benjamin Barros (2008). Barros distingue entre mecanismos estocásticos sesgados —mecanismos estocásticos que conceden a un resultado una probabilidad mayor al 50%— y mecanismos estocásticos no sesgados. Él considera que la selección natural puede ser entendida como un mecanismo estocástico sesgado. Sin embargo, su concepción de la selección natural encuentra importantes dificultades. Algunas de esas dificultades están relacionadas con la caracterización de la selección natural a nivel poblacional. Barros considera que la selección natural es un mecanismo de dos niveles; implica tanto el nivel individual como el poblacional. Y afirma que, a nivel poblacional, la selección natural tiene poblaciones como entidades componentes. Pero entender la selección natural como un mecanismo cuyas entidades componentes son poblaciones da lugar a varios problemas. Primero, identifica el objeto del fenómeno global del mecanismo con los componentes del mecanismo. Y segundo, implica aceptar que un sistema concreto —un mecanismo de selección natural— está compuesto por entidades abstractas —poblaciones— y sus relaciones.

Podría pensarse que un enfoque estocástico distinto, que eludiera los diversos problemas de la propuesta de Barros, podría dar cuenta de la selección natural y de las otras causas evolutivas. Sin embargo, difícilmente sería ese el caso. Cualquier intento de entender las causas evolutivas como mecanismos mediante un enfoque estocástico descansaría en la asunción de que esas causas son estocásticas. Y esa idea también parece problemática. El carácter estocástico de la selección natural y otras causas evolutivas (p. ej. la mutación) no está suficientemente respaldado, especialmente por parte del aparato matemático de la genética de poblaciones. En genética de poblaciones, la mayoría de las causas evolutivas son habitualmente representadas de forma determinista. Además, la práctica biológica también arroja dudas sobre la interpretación estocástica de algunas causas evolutivas. Cuando los biólogos tratan con poblaciones reales, frecuentemente entienden de manera determinista causas evolutivas como la selección natural, la migración o la mutación (e.g. Dobzhansky & Pavlovsky, 1957). Consideran que la estocasticidad de los caminos evolutivos de las poblaciones es principalmente un efecto de la deriva genética.

La *visión funcional*, inspirada por los enfoques mecanicistas funcionales (p. ej. Bechtel & Abrahamsen, 2005), trata de caracterizar la selección natural como un mecanismo MDC. Considera que la selección natural lleva a cabo una función —producir adaptación— y que ella proporciona las bases para abordar el mecanismo de selección natural. Illari y Williamson (2010) argumentan que, en la medida en que tiene una función, la selección natural puede ser descompuesta en entidades y actividades organizadas. Ellos consideran que los componentes de un mecanismo pueden ser identificados e individualizados en base a su función, es decir, su contribución a la función del mecanismo en su conjunto. Por lo tanto, dado que la selección natural tiene la función de producir adaptación, es descomponible en entidades (p. ej. organismos) y actividades (p. ej. reproducción) que contribuyen a ella. Illari y Williamson también consideran que tomando como referencia la función de un mecanismo es posible atribuirle organización. Ellos definen organización como "whatever features exist by which the activities and entities each do something and do something together to produce the phenomenon" (Illari & Williamson, 2010, p. 289). La selección natural, en la medida en que tiene una función, es un mecanismo organizado. Tomando como referencia la concepción funcional de la selección natural y las tesis defendidas por Illari y Williamson, DesAutels (2016) argumenta que la selección natural también satisface el requisito de regularidad de MDC. La selección natural es regular respecto al proceso y su regularidad no se ve amenazada por fuentes internas. DesAutels afirma que "natural selection only fails to be regular in ways that are unthreatening to its status as MDC mechanism" (DesAutels, 2016, p. 16). No siempre producir el mismo resultado y ser susceptible a fuentes externas de irregularidad no amenaza significativamente su naturaleza regular.

El principal problema de la visión funcional guarda relación con la función atribuida a la selección natural. Los defensores de la visión funcional consideran que mejorar la adaptación es la función primaria de la selección natural. Ésta es la piedra angular de su enfoque y, en última instancia, todos sus argumentos descansan sobre ella. No obstante, esta idea es muy problemática. La selección natural no necesariamente mejora la adaptación. Se trata de un resultado potencial (pero no necesario) del proceso de selección natural (Gould & Lloyd, 1999). La selección natural actúa sobre la eficacia reproductiva [*fitness*], aunque pueda indirectamente influir en otros rasgos como la capacidad para adaptarse a un determinado medio (Gillsepie, 2004). Invariablemente conduce al éxito reproductivo no arbitrario, pero solo ocasionalmente conduce a la adaptación.

La visión funcional también encontraría dificultades para dar cuenta de otras causas evolutivas. Este enfoque requeriría asignar funciones a esas causas. Sin embargo, cada causa evolutiva produce numerosos resultados y es difícil identificar uno de ellos como su función. Por ejemplo, la migración introduce variación genética en una población, reduce el grado de diferencia entre poblaciones, favorece la hibridación, etc. La visión funcional también tendría dificultades para identificar y delimitar los mecanismos evolutivos. Como se ha señalado, un mecanismo es siempre un mecanismo para un fenómeno (véase la sección 3). Y los defensores de la visión funcional consideran que un mecanismo está compuesto por las entidades, actividades y aspectos organizacionales que contribuyen al fenómeno del cual el mecanismo es responsable. Esto significa que el mecanismo responsable de cada resultado atribuido a una causa evolutiva particular sería distinto. Sin embargo, esa consideración no se ajusta a las ideas de los biólogos evolutivos; ellos consideran que el *mismo* proceso evolutivo es responsable de todos esos resultados.

Finalmente, la *visión minimalista* consiste en aplicar en biología evolutiva una noción general de mecanismo desarrollada mediante la estrategia a-través-de-las-ciencias. Glennan (2017), por ejemplo, propone una caracterización mínima que busca incluir aquello que todos los mecanismos tienen en común. Él considera que esa definición mínima es "broad enough to capture most of the wide range of things scientists have called mechanisms" (Glennan, 2017, p. 18), incluyendo los mecanismos evolutivos. Ciertamente, la noción mínima de Glennan incluye aspectos generales que están a menudo presentes en los mecanismos (p. ej. organización). Sin embargo, su propuesta no tiene en cuenta los rasgos específicos de los mecanismos evolutivos y difícilmente puede dar cuenta de ellos. Por ejemplo, la noción de Glennan de entidad (o parte) componente de un mecanismo no se ajusta a las partes de las causas evolutivas. Él afirma que las entidades deben ser estables. La estabilidad requerida depende del mecanismo en el cual están ubicadas. Una entidad componente de un mecanismo es suficientemente estable si sus propiedades y límites permanecen estables mientras tiene lugar el fenómeno del cual el mecanismo es responsable. Sin embargo, la aplicación de ese requisito a las partes de las causas evolutivas sería problemática. En primer lugar, tal y como se ha señalado, las causas evolutivas son responsables de varios fenómenos con diferentes duraciones. En consecuencia, sería muy difícil determinar que grado de estabilidad debe ser demandado a una entidad. Y, en segundo lugar, las propiedades de las partes de las causas evolutivas no siempre permanecen estables mientras tales causas y los fenómenos de los que son responsables están teniendo lugar. Por ejemplo, como resultado de la plasticidad fenotípica, el color o la altura de un organismo individual podría cambiar durante un proceso de migración (Pigliucci, 2001).

5.3. Explicaciones mecanicistas en ciencia social

La voluntad de generalidad de la nueva filosofía mecanicista encuentra importantes dificultades. Tal y como se ha mostrado, el nuevo enfoque mecanicista difícilmente puede dar cuenta de los mecanismos y sus roles en algunas áreas de la ciencia. Los mecanismos (y los roles que tienen) difieren significativamente de un campo de la ciencia a otro. Por lo tanto, las consideraciones generales que pasan por alto esta heterogeneidad son habitualmente problemáticas. Dado este escenario, parece que, para dar abordar una cuestión metodológica, es crucial tener en cuenta los rasgos específicos del área (o áreas) de interés. Este enfoque es adoptado en "Mechanistic explanations and components of social mechanisms" (anexo 3). En este artículo, discuto algunos aspectos de las explicaciones basadas en mecanismos en ciencia social, tomando la práctica de los científicos sociales como referencia. En particular, abordo la cuestión de cuales han de ser los componentes de los mecanismos sociales en las explicaciones mecanicistas de macrofenómenos sociales (en adelante "la cuestión de los componentes").

La cuestión de los componentes ha sido abordada principalmente en el marco de la sociología analítica. Una idea central de la sociología analítica es el principio de las explicaciones basadas en mecanismos (Hedström, 2005; Hedström & Bearman, 2009; Hedström & Ylikoski, 2011). Como se ha señalado en la sección 3, los sociólogos analíticos defienden la concepción mecanicista de la explicación. Consideran que un macrofenómeno social es explicado por medio de especificar el mecanismo que lo produce. El otro principio fundamental de la sociología analítica es el individualismo estructural (Hedström, 2005; Hedström & Ylikoski, 2010; Hedström & Ylikoski, 2011). Se trata de una versión débil del individualismo metodológico. El individualismo estructural considera que los macronfómenos sociales deben ser explicados en términos de interacciones entre agentes individuales. Sin embargo, a diferencia de otras versiones del individualismo metodológico, admite que no todos los hechos explicativos son sobre individuos en un sentido estricto. Las relaciones y las estructuras relacionales pueden ser explicativamente relevantes.

El principio de las explicaciones basadas en mecanismos y el individualismo estructural no se consideran independientes. Mantienen que el principio de las explicaciones basadas en mecanismos implica el individualismo estructural. El principal argumento en respaldo de esta idea es que solo hay mecanismos sociales en el nivel de los individuos (Hedström & Swedberg, 1998b; Hedström, 2005). Es decir, demandar explicaciones mecanicistas en ciencia social significa demandar explicaciones en términos de individuos, sus propiedades, sus acciones y sus relaciones. En consecuencia, sostener la concepción mecanicista de la explicación en ciencia social requeriría un compromiso con el individualismo estructural. La adopción del individualismo estructural conduce a una determinada respuesta a la cuestión de los componentes: un mecanismo social en una explicación mecanicista de un macrofenómeno social debe estar compuesto de individuos, sus propiedades, sus interacciones y sus relaciones mutuas. Esta es la posición inicial de la sociología analítica respecto de la cuestión de los componentes.

En respuesta a la posición inicial de los sociólogos analíticos en relación a la cuestión de los componentes, varios autores han cuestionado que el principio de las explicaciones basadas en mecanismos implique el individualismo estructural (Vromen, 2010; Kaidesoja, 2013). Han argumentado que no todos los mecanismos sociales se hallan en el nivel de los individuos. Hay mecanismos sociales cuyos componentes se encuentran en niveles superiores; por ejemplo, una coalición de partidos políticos. Por lo tanto, el principal argumento de los sociólogos analíticos en respaldo de la implicación entre ambos principios no se sostendría y, en consecuencia, su posición inicial respecto a la cuestión de los componentes no estaría justificada.

Dadas las críticas a su posición inicial respecto a la cuestión de los componentes, diferentes respuestas han sido dadas por los sociólogos analíticos. Michael Schmid (2011) presenta un nuevo argumento en respaldo de la posición inicial de la sociología analítica. Él también adopta el principio del individualismo estructural, el cual conduce a esa posición, pero su argumento no se basa en que solo haya mecanismos sociales en el nivel de los individuos. Primero, Schmid afirma que un aspecto de las explicaciones basadas en mecanismos en ciencia social es que requieren "*laws* indicating which factors ultimately 'produce' or 'generate' a relevant event" (2011, p. 137). En las explicaciones mecanicistas, es necesario especificar conexiones nomológicas. Y segundo, él argumenta que, estrictamente hablando, no conocemos ninguna ley social, es decir, una ley que gobierne el curso de macroprocesos sociales. En ciencia social, solo hay disponibles leyes de acción individual. A partir de esas premisas, Schmid concluye el principio del individualismo estructural respecto a las explicaciones basadas en mecanismos. El individualismo estructural, tal y como se ha señalado, conduce a la posición inicial de la sociología analítica.

El nuevo argumento planteado por Schmid es válido. La verdad de las premisas respalda la verdad de la conclusión. Si las premisas fueran verdaderas, se seguiría el principio del individualismo estructural. Sin embargo, una de las premisas del argumento es probablemente falsa. La primera premisa, que se supone que presenta un rasgo de las explicaciones basadas en mecanismos, es difícilmente correcta. Las explicaciones basadas en mecanismos no es necesario que incluyan leyes (Halina, 2018). En una explicación mecanicista, el explanandum es explicado por medio de revelar el mecanismo que es responsable de él, y para ello no hace falta especificar leyes. No es necesario mostrar que las actividades en las cuales toman parte las entidades están regidas por leyes. Por ejemplo, considere la explicación mecanicista de Mann (2004) de la propiedad de algunos países (p. ej. Gran Bretaña) en el periodo de entreguerras de no ser susceptibles de que los fascistas tomaran el poder. Él refiere a un mecanismo cuyos principales componentes son los partidos políticos de esos países y algunas de sus propiedades (p. ej. estar acostumbrados a ceder el poder soberano). Sin embargo, no se especifica ninguna conexión nomológica entre las propiedades de los partidos políticos y la susceptibilidad de los países a que los fascistas tomaran el poder.

Petri Ylikoski (2012), a diferencia de Schmid, defiende una versión modificada de la posición inicial de la sociología analítica respecto a la cuestión de los componentes. Ylikoski (2012, 2013) considera que las explicaciones mecanicistas de macrofenómenos sociales pueden ser causales o constitutivas. Y tomando esa distinción como referencia, aborda la cuestión de los componentes. En primer lugar, discute las explicaciones mecanicistas constitutivas de macrofenómenos sociales. Él considera que "[t]he *explanantia* in constitutive explanations are always at the micro level" (Ylikoski 2012, p. 35). Por lo tanto, afirma que en las explicaciones mecanicistas constitutivas los componentes de los mecanismos sociales han de hallarse a nivel micro. En segundo lugar, Ylikoski aborda las explicaciones mecanicistas causales de macrofenómenos sociales. Él reconoce que, en las explicaciones causales, el explanans no está siempre a nivel micro. Sin embargo, considera que las explicaciones mecanicistas causales de macrofenómenos sociales requieren "microfundamentos". Apelar a entidades, propiedades, actividades y relaciones de nivel micro es esencial para entender como se mantienen las relaciones causales de dependencia contrafáctica. En consecuencia, argumenta que en las explicaciones mecanicistas causales los componentes de los mecanismos deben hallarse a nivel micro. Ylikoski concluye que, en las explicaciones mecanicistas (constitutivas o causales) de macrofenómenos sociales, los mecanismos sociales han de estar compuestos de entidades, propiedades, actividades y relaciones de nivel micro.

La propuesta de Ylikoski es menos rígida que la posición inicial de la sociología analítica respecto a la cuestión de los componentes. Él mantiene que los componentes de los mecanismos sociales han de ser entidades, propiedades, actividades y relaciones a nivel micro. Sin embargo, considera que no hay un único y predeterminado nivel micro. La distinción entre micro y macro es entendida como una cuestión de escala. Qué se considera como un microcomponente depende del fenómeno explanandum (y de los intereses explicativos). La propuesta perspectivista de Ylikoski evita las principales dificultades de la posición inicial de la sociología analítica —es compatible con el hecho de que no todos los mecanismos sociales se hallen al nivel de los individuos— y del argumento de Schmid —no demanda que las explicaciones mecanicistas incluyan leyes—. No obstante, su propuesta también tiene problemas relevantes.

El principal problema de la propuesta de Ylikoski es que es muy vaga y, en consecuencia, no constituye una respuesta adecuada a la cuestión de los componentes. La noción de 'nivel micro' no es caracterizada adecuadamente. La relación micro-macro es definida como un tipo particular de diferencia de escala, pero no se especifican con claridad los rasgos que la caracterizan y la distinguen de otras diferencias de escala. Otro aspecto problemático de la propuesta de Ylikoski es que no proporciona una guía para la construcción de explicaciones mecanicistas. Por un lado, tal y como se ha señalado, no es lo suficientemente concreta. Nunca es seguro si cierto componente se halla en el nivel micro o no. Y, por otro lado, para identificar el nivel micro haría falta especificar previamente el explanans y el explanandum. Para pertenecer al nivel micro, un componente debe ser explicativamente relevante para el macrofenómeno explanandum. Finalmente, la propuesta de Ylikoski no se ajusta a muchas explicaciones de macrofenómenos sociales basadas en mecanismos. En ciencia social, las explicaciones mecanicistas causales de macroeventos a menudo incluyen entidades, propiedades, actividades o relaciones que difícilmente se hallan a nivel micro. Por ejemplo, considere la explicación mecanicista que McCright y Dunlap (2003) dan de la no ratificación del Protocolo de Kioto por parte del senado de los EUA. Ellos especifican como los *think tanks* conservadores (y su colaboración con los escépticos del cambio climático) produjeron la redefinición del calentamiento global como no problemático, y como esta redefinición influyó en la arena política y condujo a la no ratificación del protocolo. En la explicación de McCright y Dunlap la mayoría de los componentes del mecanismo social (p. ej. *think tanks*) difícilmente se hallan en el nivel micro respecto del explanandum (la no ratificación del Protocolo de Kioto por parte del senado de los EUA).

No hay un nivel privilegiado al cual deban pertenecer siempre los componentes de los mecanismos sociales en las explicaciones mecanicistas de macrofenómenos sociales. Ni en las explicaciones mecanicistas causales ni en las explicaciones mecanicistas constitutivas, los componentes de los mecanismos sociales deben hallarse siempre en un determinado nivel. Dado este escenario, podría pensarse que no es posible dar una respuesta adecuada a la cuestión de los componentes. Parece que las propuestas que dan cuenta de la diversidad de las explicaciones mecanicistas (como la propuesta de Ylikoski) son demasiado vagas e incapaces de ofrecer una guía para la construcción de explicaciones, mientras que las propuestas concretas y operativas (como la posición inicial de la sociología analítica) no se ajustan a la diversidad de las explicaciones mecanicistas. Sin embargo, considero que puede plantearse un requisito mínimo, el cual sea concreto y operacional sin ignorar la diversidad de las explicaciones mecanicistas, respecto de los componentes de los mecanismos sociales. En particular, un componente de un mecanismo social en una explicación mecanicista de un macrofenómeno social no debe tener el fenómeno explanandum como parte.

El requisito mínimo se aplica tanto a las explicaciones mecanicistas causales como constitutivas de macrofenómenos sociales. En las explicaciones mecanicistas causales, los componentes del mecanismo no deben tener el fenómeno explanandum como parte. Para ser un componente del mecanismo, una entidad o una actividad (u otro tipo de componente) debe ser causalmente relevante para el fenómeno explanandum. Sin embargo, no puede haber una relación de dependencia causal entre ellos si la entidad o la actividad tiene al fenómeno explanandum como parte. No es posible una relación de dependencia causal entre un todo y una de sus partes (Hitchcock, 2003; Craver & Bechtel, 2007). Análogamente, en las explicaciones mecanicistas constitutivas, los componentes del mecanismo no deben tener el fenómeno explanandum como parte. En este tipo de explicaciones, los componentes del mecanismo deben ser partes propias del sistema cuya propiedad o comportamiento es el fenómeno explanandum (Craver, 2007). Sin embargo, un componente no puede ser parte propia del sistema cuya propiedad o comportamiento es el fenómeno explanandum si ese fenómeno es parte de él. Si el fenómeno de interés es parte del componente, el sistema cuya propiedad o comportamiento es tal fenómeno es también parte del componente. Y si el sistema es parte del componente, el componente no puede ser parte propia del sistema.

6. Explicaciones mecanicistas y negacionismo de la ciencia

El negacionismo de la ciencia es una forma conocida de pseudociencia. A diferencia de la promoción de pseudoteorías, el negacionismo no se centra en promocionar una determinada teoría (p. ej. la ley de la similitud), sino en negar cierta afirmación científica. El negacionismo de la ciencia consiste en el rechazo sistemático de cierta idea con respecto a la cual existe consenso en la comunidad científica (Diethelm & Mckee, 2009;

Liu, 2012; Hansson, 2017). Normalmente tiene por objeto afirmaciones que cuestionan el estilo de vida de la gente o su visión del mundo, o que amenazan los intereses de las grandes corporaciones (Lewandowsky et al., 2016). Algunos ejemplos destacados son el negacionismo de las enfermedades asociadas al tabaco, el negacionismo de la evolución y el negacionismo del cambio climático.

Aunque no es un movimiento homogéneo, hay cinco características epistemológicas que están presentes en todos los casos de negacionismo de la ciencia (Liu, 2012; Hansson, 2017, 2018). Primero, en sus argumentos se emplea constantemente la selección interesada de datos; solo se tiene en consideración una pequeña parte de la evidencia disponible. Segundo, los negacionistas se muestran reacios a abandonar ideas y argumentos, incluso aunque éstos hayan sido refutados. Tercero, se fabrican falsas controversias. Se afirma que cierta cuestión es objeto de controversia entre los científicos, a pesar de que existe un gran consenso al respecto en la comunidad científica. Cuarto, se introducen criterios de aceptación sesgados. Los negacionistas establecen estándares de evidencia poco realistas, los cuales difícilmente pueden ser satisfechos por la investigación científica actual. Y quinto, se representa inadecuadamente la propuesta contraria. La idea científica es distorsionada, por ejemplo, sacando citas fuera de su contexto. También hay varias características sociológicas que están a menudo presentes en el negacionismo de la ciencia (Diethelm & Mckee, 2009; Liu, 2012; Hansson, 2017, 2018). Por ejemplo, el negacionismo suele tener fuertes vínculos políticos (p. ej. el negacionismo de la evolución está relacionado con el ala conservadora cristiana). Otras características sociológicas que están frecuentemente presentes en el negacionismo de la ciencia son: estar respaldado principalmente por hombres, dirigiste a la gente común en lugar de los investigadores, y atacar personal y profesionalmente a los científicos individuales.

Un tipo relevante de negacionismo de la ciencia, el cual no ha sido abordado con anterioridad, son las ‘guerras de explicación’. En “Mechanisms and science denialism: explaining the global lung cancer epidemic” (anexo 4), esta forma de pseudociencia es caracterizada y discutida. Una *guerra de explicación* es una situación en la que (i) hay un fenómeno que no se cuestiona (p. ej. la creciente incidencia de una enfermedad), (ii) en la comunidad científica existe consenso respecto a su explicación y (iii) la explicación científica estándar es sistemáticamente negada por un grupo de personas. Con el fin de socavar la explicación de la ciencia convencional, los negacionistas suelen seguir dos estrategias. Por un lado, atacan directamente la explicación estándar. Por ejemplo, afirman que la relación causal entre explanans y explanandum no ha sido demostrada con un cien por cien de seguridad (Proctor, 2011; Prothero, 2013). Por otro lado, los negacionistas proponen y promueven explicaciones alternativas, la cuales se presentan como igual de legítimas que la estándar, para aumentar la controversia y hacer su posición más creíble (Proctor, 2004, 2011; Pearl & Mackenzie, 2018). Por ejemplo, financian la investigación privada que estudia alguna explicación alternativa mínimamente plausible. En las guerras de explicación, están presentes los rasgos distintivos del negacionismo de la ciencia. Estrategias tales como introducir criterios sesgados de aceptación y fabricar falsas controversias tienen un papel central en la ofensiva contra la explicación estándar.

La concepción mecanicista de la explicación es de ayuda para hacer frente a las guerras de explicación. En una guerra de explicación, la explicación estándar de un fenómeno es negada por un grupo de personas. No obstante, si la explicación estándar es mecanicista, la ofensiva de los negacionistas es menos efectiva. Las explicaciones basadas en mecanismos son resistentes a los argumentos generalmente utilizados por los negacionistas. Como se ha señalado, para socavar la explicación de la ciencia convencional, los negacionistas siguen dos estrategias. Primero, atacan directamente la explicación estándar. Los negacionistas argumentan que esa explicación no prueba satisfactoriamente la conexión causal entre explanans y explanandum. Sus argumentos se basan en "an extraordinarily narrow and mechanical conception of causation" (Proctor, 2011, p. 275). Segundo, los negacionistas proponen y promueven explicaciones alternativas para aumentar la controversia. Las explicaciones alternativas, las cuales son presentadas como igual de legítimas que la estándar, suelen basarse en correlaciones estadísticas entre el fenómeno explanandum y variables no incluidas en la explicación de la ciencia convencional (Proctor, 2004, 2011). Sin embargo, las estrategias seguidas por los negacionistas son poco efectivas frente a explicaciones mecanicistas. Por un lado, las explicaciones mecanicistas establecen el vínculo (causal o constitutivo) entre explanans y explanandum. Muestran cómo surge el fenómeno de interés. Por otro lado, las explicaciones alternativas planteadas por los negacionistas no son explicaciones legítimas al mismo nivel que la explicación estándar. No suelen ser explicaciones mecanicistas, sino explicaciones de caja negra que no abordan la conexión entre explanans y explanandum, y que no están respaldas por el mismo tipo de evidencia que la explicación convencional.

La relevancia de las explicaciones mecanicistas y su resistencia a los ataques negacionistas pueden ilustrarse a través de la guerra de explicación relativa a la epidemia global de cáncer de pulmón. Al principio del siglo veinte, el cáncer de pulmón era una enfermedad extraordinariamente rara (Proctor, 2001, 2011, 2012). Solo se habían registrado unos pocos cientos de casos en la literatura médica mundial. Sin embargo, durante las primeras décadas del siglo veinte se detectó en varios países un incremento en la incidencia del cáncer de pulmón. Este dramático cambio demandaba una explicación. A lo largo de las siguientes décadas, se discutieron varias explicaciones posibles de la epidemia. Entre los diversos factores que fueron tenidos en cuenta estaban la contaminación atmosférica, las exposiciones laborales y la creciente popularidad de los cigarrillos (Proctor, 2004, 2011). Finalmente, en la década de 1950, la idea de que el consumo de tabaco explicaba la epidemia de cáncer de pulmón tomó la delantera. La conexión causal entre los cigarrillos y el cáncer de pulmón fue establecida por medio de cuatro líneas directas de evidencia: estudios poblacionales, experimentos con animales, patología celular y análisis químicos (Proctor, 2012). Y, como resultado de este conocimiento causal, se estableció un amplio consenso entre los expertos de que el consumo de tabaco daba cuenta de la epidemia global de cáncer de pulmón (Proctor, 2011, 2012).

Hacia mediados de la década de 1950, había consenso entre los científicos de que el consumo de tabaco explicaba la epidemia global de cáncer de pulmón. Sin embargo, la industria tabacalera sistemáticamente negaba esa explicación. Aunque ellos aceptaban que la incidencia del cáncer de pulmón había aumentado y que eso demandaba una explicación, rechazaban la explicación que vinculaba esa epidemia con su producto. Para socavar la explicación estándar, la industria tabacalera siguió dos estrategias. En primer lugar, atacó la explicación de la ciencia convencional (Proctor, 2011). Su principal argumento era que la conexión causal no había sido establecida de forma conclusiva y que hacía falta más investigación. En segundo lugar, la industria tabacalera promovía explicaciones alternativas de la epidemia global de cáncer de pulmón (Proctor, 2004, 2011). Por medio de instituciones como el Council for Tobacco Research y el Tobacco Institute, financiaba y publicitaba la investigación orientada a descubrir posibles causas del cáncer de pulmón distintas al tabaco.

A principios de la década de 1990, se descubrieron los mecanismos que vinculan el consumo de cigarrillos y el cáncer de pulmón. La explicación estándar de la epidemia global de cáncer de pulmón pasó a ser mecanicista (Russo & Williamson, 2007). Ésta detallaba los procesos a través de los cuales fumar produce cáncer de pulmón. Como consecuencia de ello, las estrategias de la industria tabacalera perdieron su efectividad.

Por un lado, la explicación estándar establecía conclusivamente la conexión causal entre fumar y el cáncer de pulmón. Se ajustaba a la estrecha concepción mecanicista de la causalidad adoptada por los negacionistas y hacía obsoleto el argumento de 'más investigación'. Por otro lado, la explicación estándar se distinguía con claridad de las explicaciones alternativas. Era una explicación mecanicista causal, mientras que las alternativas eran explicaciones estadísticas o explicaciones causales no mecanicistas. En la década de 1990, tras esa pérdida de eficacia, la industria tabacalera cambió su estrategia y dejó de negar la explicación que la ciencia convencional daba de la epidemia global de cáncer de pulmón (Proctor, 2001, 2006, 2011). Aceptaron que el tabaco era un factor de riesgo en el desarrollo de cáncer de pulmón y que su consumo explicaba la alta incidencia del cáncer de pulmón. A partir de ese momento, su estrategia legal fue argumentar que "the risks of smoking have been well-known for decades, and that people therefore voluntarily assume such risks when they take up the habit" (Proctor, 2001, p. 84).

7. Conclusiones

Los mecanismos tienen un papel central en la empresa científica. Desde la biología molecular hasta la sociología, los científicos de diversos campos recurren a mecanismos para describir, explicar, predecir y controlar los fenómenos del mundo. La relevancia de los mecanismos y de los enfoques que apelan a mecanismos no ha pasado desapercibida para los filósofos. Como se ha señalado, la primera filosofía mecanicista se remonta a la Grecia clásica. La filosofía mecanicista gozó de gran popularidad durante la segunda mitad del siglo diecisiete. En ese periodo, la filosofía mecanicista se convirtió en el enfoque dominante en la filosofía natural y la filosofía de la ciencia. No obstante, aunque no tan influyentes, numerosas propuestas mecanicistas han sido defendidas posteriormente en filosofía.

En el contexto filosófico actual, la nueva filosofía mecanicista es el principal representante del enfoque mecanicista. Igual que la filosofía mecanicista del siglo diecisiete, es tanto una filosofía de la ciencia como una filosofía natural. La nueva filosofía mecanicista no solo está interesada en la metodología científica, sino también en la constitución y organización del mundo. Se considera que los mecanismos son uno de los principales constituyentes del mundo. Sin embargo, tal y como se ha indicado, la nueva filosofía mecanicista se caracteriza por un énfasis generalizado en la práctica científica real. Su objeto de interés primero es el mecanismo como concepto-en-uso en la ciencia. Los nuevos mecanicistas se fijan en la práctica científica y la toman como referencia para abordar tanto las cuestiones metodológicas como las ontológicas.

La nueva filosofía mecanicista ha demostrado ser un enfoque muy fructífero en filosofía de la ciencia. Ha dado lugar a un progreso significativo en diferentes discusiones filosóficas. Dentro del marco de la nueva filosofía mecanicista, se han abordado convincentemente la explicación científica (Machamer et al., 2000; Bechtel & Abrahamsen, 2005), la inferencia causal (Steel, 2004; Russo & Williamson, 2007; Parkkinen et al., 2018), la extrapolación de relaciones causales (Steel, 2008; Wilde & Parkkinen, 2019), la investigación científica (Bechtel & Richardson, 1993; Darden, 2018), el crecimiento y la organización del conocimiento (Hedström & Ylikoski, 2010; Glennan, 2017) y varias otras cuestiones. Como se argumenta en "Mechanisms and science denialism: explaining the global lung cancer epidemic" (anexo 4), la nueva filosofía mecanicista también podría contribuir a combatir la pseudociencia. El nuevo enfoque mecanicista es de ayuda para lidiar con ciertas formas de negacionismo de la ciencia. Es especialmente valioso en las guerras de explicación. La nueva concepción mecanicista de la explicación científica proporciona explicaciones resistentes a los argumentos habitualmente utilizados por los negacionistas. Además, la nueva filosofía mecanicista ofrece un enfoque prometedor para abordar otras cuestiones como la evaluación de riesgos (Rocca, 2017; Rocca et al., 2020), la comprensión pública de la ciencia (Lewandowsky & Oberauer, 2016) y la evaluación ética y de bienestar (Grüne-Yanoff, 2016).

No obstante, la nueva filosofía mecanicista también tiene ciertos aspectos problemáticos. Algunos de estos problemas guardan relación con la voluntad de generalidad y amplia aplicabilidad. Los mecanismos son relevantes en la mayoría de las áreas científicas, y la nueva filosofía mecanicista quiere plantear un enfoque mecanicista general que las englobe a todas ellas. Sin embargo, encuentra importantes dificultades para dar cuenta de los mecanismos y sus roles en algunos campos. Una de esas dificultades, la cual es abordada en "The Search for Generality in the Notion of Mechanism" (anexo 1), está relacionada con la noción misma de mecanismo. Los nuevos mecanicistas tratan de desarrollar una noción general de mecanismo apropiada para toda la gama de mecanismos estudiados en las ciencias. El desarrollo de una noción general es perseguido con diversas estrategias —la estrategia de extrapolación y la estrategia a-través-de-las-ciencias—. Sin embargo, todas ellas han resultado infructuosas. Son incapaces de proporcionar una noción de mecanismo que de satisfactoriamente cuenta de todos los tipos de mecanismo. Además, es dudoso que una noción general de mecanismo adecuada pueda ser desarrollada. Los fenómenos, las entidades, las actividades y los aspectos organizacionales estudiados por las diferentes ciencias son tan heterogéneos que una noción de mecanismo que sea informativa y recoja todos los casos relevantes parece inalcanzable.

Uno de los principales avances de la nueva filosofía mecanicista es prestar atención a la práctica científica real. Considerar los mecanismos como concepto-en-uso en la ciencia ha sido crucial para muchas de sus contribuciones (p. ej. analizar el descubrimiento científico). Sin embargo, parece que la nueva filosofía mecanicista no advierte las relevantes diferencias entre los campos científicos. No tiene en consideración las particularidades de los mecanismos y sus roles en cada área. En consecuencia, el enfoque mecanicista encuentra importantes problemas para ser ampliamente aplicado. Por ejemplo, como se discute en "Evolutionary causes as mechanisms: a critical analysis" (anexo 2), ignorar las particularidades de los mecanismos evolutivos hace inadecuados los acercamientos mecanicistas a la biología evolutiva. Para superar estas dificultades, la nueva filosofía mecanicista debe abandonar la ingenua asunción de similitud y tener en cuenta la especificidad de los diversos campos científicos. Cuando una cuestión metodológica es abordada, inicialmente debería adoptarse un enfoque específico de área. En cada campo relevante, la cuestión debería ser abordada tomando como principal referencia la práctica de los científicos implicados. No basta con tener en cuenta la práctica científica, hay que tener en cuenta la práctica científica pertinente. Este enfoque específico de área es adoptado en "Mechanistic explanations and components of social mechanisms" (anexo 3). En este artículo, tomando la práctica de los científicos sociales como referencia, se aborda la cuestión de cuales han de ser los componentes de los mecanismos sociales en las explicaciones mecanicistas de macrofenómenos sociales.

El enfoque específico de área facilitaría la aplicación de la nueva filosofía mecanicista a otros campos de la ciencia. Hay campos científicos que difieren significativamente de las áreas inicialmente consideradas por los nuevos mecanicistas y cuyas particularidades deberían ser consideradas. Este es el caso, por ejemplo, de la psicología (Kazdin, 2007; Koch & Cratsley, 2020). Los mecanismos estudiados por los psicólogos tienen muchas diferencias importantes con los mecanismos biológicos y sociales. Además, la orientación específica de área permitiría al nuevo enfoque mecanicista abordar exitosamente problemas específicos de determinadas áreas, como la generalización a partir de casos de estudio en ciencia social (Ylikoski, 2019).

Reconocer la diversidad de los campos científicos respecto a como son entendidos los mecanismos y que roles juegan (o podrían jugar) no significa renunciar a la voluntad de generalidad. La nueva filosofía mecanicista podría desarrollar un enfoque mecanicista amplio que se ajustara a todos los campos en que los mecanismos son relevantes. De hecho, este tipo de enfoque sería muy útil para abordar problemas filosóficos generales y facilitar la colaboración entre campos. Admitir la especificidad de los campos científicos solo significa que las consideraciones generales no pueden pasar por alto como los mecanismos y sus roles son entendidos en las diversas áreas de la ciencia. El enfoque mecanicista global debe construirse sobre la base de las discusiones específicas de área del mecanismo como concepto-en-uso en la ciencia.

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Annexes

Annex 1: Pérez-González, S. (2019). The Search for Generality in the Notion of Mechanism. *Teorema: Revista internacional de filosofía*, *38*(3), 77-94.

Annex 2: Pérez-González, S., & Luque, V. J. (2019). Evolutionary causes as mechanisms: a critical analysis. *History and philosophy of the life sciences*, *41*(2), 13.

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The Search for Generality in the Notion of Mechanism

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RESUMEN

En este artículo, introduzco y analizo un principio general compartido por los nuevos mecanicistas: *la búsqueda de generalidad*. Los nuevos mecanicistas consideran que una noción de mecanismo aceptable ha de ser adecuada para la mayoría de las áreas científicas en que los mecanismos son relevantes. El desarrollo de nociones de mecanismo generales se lleva a cabo mediante dos estrategias diferentes y alternativas, a las cuales denomino *la estrategia de extrapolación* y *la estrategia a-través-de-las-ciencias*. Después de analizar ejemplos paradigmáticos de éstas, planteo que ambas estrategias tienen problemas significativos y que las posibilidades de superarlos son escasas. Se concluye que sería recomendable abandonar la búsqueda de generalidad.

PALABRAS CLAVE*: mecanismo, explicación científica, generalidad, mecanismo de transmisión monetaria, selección natural.*

ABSTRACT

In this paper, I introduce and discuss a general principle shared by new mechanists: *the search for generality*. New mechanists agree that an appropriate notion of mechanism has to be suitable for most of the fields of science where mechanisms are relevant. The development of general notions of mechanism is pursued with two different and alternative strategies, which I call *the extrapolation strategy* and *the across-the-sciences strategy*. After analysing paradigmatic examples of them, I argue that both strategies face outstanding difficulties and that the prospects for overcoming them are dim. It is concluded that it would be advisable to abandon the search for generality.

KEYWORDS: *Mechanism, Scientific Explanation, Generality, Monetary Transmission Mechanism, Natural Selection.*

I. INTRODUCTION

The new mechanism emerged in the mid-90s.[1] *Discovering Complexity: Decomposition and Localization as Strategies in Scientific Research* (1993) by William Bechtel and Robert C. Richardson marked the beginning of this approach. Although it became much more influent some years later with the publication of "Mechanisms and the Nature of Causation" (1996) by Stuart Glennan and "Thinking about Mechanisms" (2000) by Peter Machamer, Lindley Darden, and Carl F. Craver (henceforth MDC). The new mechanism is both a philosophy of science (i.e. philosophical inquiry into science) and a philosophy of nature (i.e. philosophical inquiry into the constituents of real things). Not only is it concerned about the role of mechanisms in science, but also about the nature of mechanisms, which are part of the real world.

The aim of this paper is to discuss a general principle of the new mechanism that I call *the search for generality*. Its structure is as follows. Section II introduces the main features of the new mechanism. Section III characterizes the search for generality and the two strategies that are adopted in order to achieve that purpose. Section IV argues that both strategies for achieving generality face outstanding difficulties. Section V shows that the problems of the search for generality undermine some arguments in support of the mechanistic approach (e.g. the mechanistic account of explanation). Finally, section VI concludes.

II. The New Mechanism

Within the framework of the new mechanism, several proposals have been raised. The most relevant ones are those of Glennan (1996), (2002), (2017), MDC (2000), Bechtel and Abrahamsen (2005), (2010), and Illari and Williamson (2012). In spite of the disagreements among those proposals, some general ideas are shared by all of them. Recent books such as *The New Mechanical Philosophy* (2017) by Glennan and *The Routledge Handbook of Mechanisms and Mechanical Philosophy* (2018) edited by Glennan and Illari have underlined the great deal of consensus existing within the new mechanism.

New mechanists consider that a mechanism is an organized compound that is part of the real world. They discriminate between a mechanism, which is a real entity, and a model of it, which is often a piece of scientific reasoning. In this sense, Glennan says that "mechanisms and their constituents are things in the world that exist independently of the models we made of them" [Glennan (2017), p. 10]. They also agree that mechanisms are nested and form a hierarchy [Machamer, Darden, and Craver (2000), p. 13]. A component part of a mechanism is often a mechanism itself. For instance, a heart is both a mechanism and a component part of a mechanism (e.g. a circulatory system). Nevertheless, this idea does not lead them to reductionism regarding mechanisms. They reject that it is possible to reduce higher level mechanisms to lower level mechanisms [Andersen (2014), p. 281]. Another shared idea is that a mechanism is always a mechanism for some phenomenon [Bechtel and Abrahamsen (2005), p. 42; Craver (2007), p. 123; Glennan (1996), p. 52]. The identification and delimitation of a mechanism (i.e. the fixation of a mechanism's boundaries) depend on the phenomenon for which it is responsible [Kaiser (2018)]. In the new mechanism, the notion of mechanism is not equivalent to the notion of machine. Although human-built machines (e.g. a vending machine) can often be considered mechanisms, most mechanisms are not machines.

There are also some general agreements regarding the principles that guide new mechanists' research. All their proposals emerge form a focus on scientific practice [Glennan (2017), p. 12]. Scientists' considerations about mechanisms are the main reference for the development of new mechanists' notions of mechanism. Another shared trait is the interest in how the discovery and decomposition (i.e. the identification of components and their organization) of mechanisms works [Bechtel and Richardson (1993); Darden (2018)]. They are not only interested in the role of mechanisms in science, but also in how scientists discover and decompose them. Due to the fact that a mechanism is always a mechanism for some phenomenon, the discovery of a mechanism begins with the identification of a puzzling phenomenon.

According to the new mechanism, the role of mechanisms in science is usually associated with the scientific objective of explaining. New mechanists have developed a mechanistic account of scientific explanation. They consider that a phenomenon is explained by means of specifying the mechanism that is responsible for it.[2] In this sense, MDC say: "To give a description of a mechanism for a phenomenon is to explain that phenomenon" [Machamer, Darden, and Craver (2000), p. 3]. A well-known example of mechanistic explanation is the standard explanation of the phenomenon of chemical transmission at synapsis [Machamer, Darden, and Craver (2000)]. This phenomenon is explained by the interactions (e.g. transporting, inserting, diffusing…) among cell membrane, vesicles, microtubules, molecules, and ions that are responsible for it. The mechanistic approach to scientific explanation has been developed as an alternative to the covering-law model [Bechtel and Abrahamsen (2005); Craver (2014)].[3] The covering-law model, which was developed by Carl G. Hempel (1965), is based on the idea that to explain a phenomenon is to subsume it under a law. This proposal gave rise to a consensus regarding the notion of scientific explanation that lasted from the late 1940s to the mid-1960s [Salmon (1989), p. 3]. However, since the early 1960s, several critiques and counterexamples have noted that subsuming a phenomenon under a law is neither necessary nor sufficient condition for explaining it. The mechanistic approach, as other current approaches (e.g. unificationist account of explanation, pragmatic theories of explanation…), try to account for scientific explanation avoiding covering-law model's problems.

New mechanists consider that mechanisms are relevant in science and that their relevance is manly associated with explaining. Thus, they support a mechanistic account of scientific explanation. According to it, a phenomenon is explained by means of specifying the mechanism that is responsible for it. In what follows, I will discuss one problematic aspect of the new mechanism related to the notion of mechanism, i.e., the search for generality.

III. The Search for Generality

Through the previous section, several well-known general principles of the new mechanism have been noted. Nevertheless, there is another one that has not been previously identified and deserves attention. It is *the search for generality*. New mechanists consider that mechanisms are relevant in most scientific fields. And they agree that an appropriate notion of mechanism has to be suitable for most of the fields where mechanisms are relevant. In this sense, in his foundational "Mechanisms and the Nature of Causation", Glennan [(1996), p. 50] claims that mechanisms are relevant in all scientific fields except fundamental physics. His proposal aims to suit those fields.

Despite the fact that the search for generality is a trait shared by all mechanistic proposals, it is not always pursued with the same strategy. This difference with respect to the strategies has made difficult to identify this common feature. Within the new mechanism, there are two strategies for proposing general notions of mechanism. I call them *the extrapolation strategy* and *the across-the-sciences strategy*.

The extrapolation strategy consists of developing a notion of mechanism taking one or a few fields of science as reference, and then applying that notion to many other fields. This strategy goes from certain kind of mechanisms to a general notion of mechanism, so that, the notion is applied to kinds of mechanisms that were not taken into account for its development. MDC (2000), for instance, follow the extrapolation strategy. Their notion of mechanism was developed taking neurobiological and molecular mechanisms as reference. The mechanisms of chemical transmission at synapsis and protein synthesis are their paradigmatic examples of mechanisms. But they consider that their notion of mechanism could be applied to other fields of science. In this sense, they say: "We suspect that this analysis is applicable to many other sciences, and maybe even to cognitive or social mechanisms" [Machamer, Darden, and Craver (2000), p. 2].[4] The extrapolation strategy was also adopted by Glennan (1996), (2002). He developed his notion of mechanism taking physical mechanisms (e.g. a float valve, a voltage switch…) as reference. Nevertheless, he considered that it suited many other kinds of mechanisms: "my analysis is in no way limited to mechanisms that are physical in nature. It is meant to equally apply to chemical, biological, psychological and other higher-level mechanisms" [Glennan (1996), p. 61].

James Woodward (2002) also follows the extrapolation strategy in his study of mechanisms.[5] He focuses on mechanics (e.g. a block sliding down an inclined plane), although he takes into account molecular biology too. However, he claims that "a notion of mechanism very similar to that characterized by **MECH** is employed in many other fields of science — for example, in psychology" [Woodward (2002), p. S376].

The across-the-sciences strategy consists of thinking about mechanisms across all the sciences and developing a notion of mechanism that includes their common features. This strategy goes from all mechanisms to a general notion of mechanism. All kinds of mechanisms to which the notion is applied are taken into account for its development. The across-the-sciences strategy was introduced by Illari and Williamson (2012), who underlined its difference from the previous developments of notions of mechanism (i.e. the extrapolation strategy). Their aim is to consider mechanisms in general and to propose "a characterization that gives an understanding of what is common to mechanisms in *all* fields" [Illari and Williamson (2012), p. 120]. They underline the need of a consensus account of mechanisms in order to address several philosophical issues (e.g. causal explanation, inference, and modelling). The across-the-sciences strategy has recently been adopted by Glennan (2017). He has abandoned his previous notion of mechanism [see Glennan (1996), (2002)] and proposes a minimal characterization of it, which tries to include what all mechanisms share in common. His aim is to develop a notion of mechanism "broad enough to capture most of wide range of things scientists have called mechanisms" [Glennan (2017), p. 18]. In the next section, I will show that both the extrapolation strategy and the across-the-sciences strategy face outstanding difficulties.

IV. THE DIFFICULTIES OF THE SEARCH FOR GENERALITY

Generality is a valuable purpose here. There are several kinds of mechanisms in science (e.g. molecular mechanisms, social mechanisms, computing mechanisms…). A notion that could account for all of them would be useful for both scientific research and philosophical understanding. It would facilitate collaboration among fields of science where mechanisms are relevant. Besides, the will of generality is also present in many philosophical issues related with mechanisms. For instance, philosophers of science try to develop a notion of causal explanation that suits all explanations where the *explanans* makes reference to the causes of the *explanandum* phenomenon. A general notion of mechanism would help to address these issues. However, I will argue below that both suggested strategies for pursuing generality face outstanding difficulties. In order to identify and analyse those difficulties, I will focus on MDC's and Illari and Williamson's proposals, which are paradigmatic examples of the extrapolation strategy and the across-the-sciences strategy respectively.

IV.1. *The Difficulties of the Extrapolation Strategy*

MDC's proposal, one of the most relevant ones in the current debate, follows the extrapolation strategy for developing a general notion of mechanism. However, their notion of mechanism, which is developed taking certain kind of mechanisms as reference, does not suit many other kinds of mechanisms. MDC define mechanism as follows:

> Mechanisms are entities and activities organized such that they are productive of regular changes from start or set-up to finish or termination conditions [Machamer, Darden, and Craver (2000), p. 3].

A mechanism is an organized collection of entities (with their properties) and activities. Entities are things that engage in activities. They are usually spatiotemporal located, structured, and oriented. Examples of entities are neurotransmitters, neurons, DNA bases… Activities are productive happenings. They have temporal order, rate, and duration. Examples of activities are transporting, neuromodulating, recycling… Mechanisms' components are organized. Their organization has temporal, spatial, and active aspects [Craver and Darden (2013), p. 20]. MDC hold that mechanisms are regular and "work always or for the most part in the same way under the same conditions" [Machamer, Darden, and Craver (2000), p. 3].

Although MDC consider that their notion of mechanism could be applied to most fields of science (see section III), it is unlikely the case. For instance, the application of MDC's notion of mechanism to evolutionary biology would be very problematic. Evolutionary biologists often refer to evolutionary causes (e.g. natural selection, mutation, migration…) as mechanisms that bring about changes in populations. In this sense, Graham Bell says: "Selection is an effective mechanism for producing adaptation" [Bell (2008), p. 499]. Other evolutionary biologists who refer to several evolutionary causes as mechanisms are Jon C. Herron and Scott Freeman (2014). However, MDC's notion of mechanism is not able to account for evolutionary causes as mechanisms. Robert A. Skipper and Roberta L. Millstein (2005) have argued that natural selection does not meet MDC's characterization of mechanisms.[6] For instance, relevant productive relationships among component entities of natural selection cannot always be understood as activities. Natural selection often depends on passive selection processes (e.g. being poisonous, having certain colour…) that can hardly be considered activities. Skipper and Millstein also say that natural selection does not satisfy the requirement of regularity.[7]

MDC's notion of mechanism is also unable to account for economic mechanisms. Economists often refer to economic mechanisms (e.g. markets, price mechanisms…). Well-known examples of economic mechanisms are monetary transmission mechanisms. A monetary transmission mechanism is a mechanism responsible for the influence of a central bank in output, employment, prices, and inflation of a country or a political and economic union (e.g. European Union) [Samuelson and Nordhaus (2010), p. 484]. It is an organized collection of entities (e.g. banks, central banks, securities broker-dealers…) and activities (e.g. buying and selling government securities, trading reserve balances at a central bank, changing the legal reserve-ratio requirements…). It could seem that MDC's notion of mechanism suits monetary transmission mechanisms, but it is unlikely the case.

MDC consider that mechanisms are regular. Lane DesAutels (2016) has recently showed that in order to meet MDC's requirement of regularity a mechanism has to be process regular and not be affected by internal sources of irregularity. However, monetary transmission mechanisms are not process regular and are affected by internal sources of irregularity. Process regularity consists in that "the constituent entities and activities of a mechanism behave in roughly the same way each time the mechanism operates" [DesAutels (2016), p. 16]. But, component entities of monetary transmission mechanisms do not always behave in the same way. For instance, given an undesirably low level of inflation, a central bank (e.g. European Central Bank, U.S. Federal Reserve System…) does not always behave in the same way in order to influence in it. Central banks often buy government securities for increasing the level of inflation. But sometimes they also modify the reverse-ratio requirements or borrow money with a discount rate. Monetary transmission mechanisms are affected by internal sources of irregularity too. For example, a change in the behaviour of the U.S. Federal Reserve System can be the result of a change in which presidents of regional Federal Reserve Banks are voting members of the Federal Open Market Committee.

Other aspect of MDC's proposal that does not suit monetary transmission mechanisms is the fixation of mechanisms' boundaries. It is considered that "mechanisms are always mechanisms *of* a given phenomenon" [Craver (2007), p. 123]. Regarding boundaries, Craver says: "The boundaries of mechanisms —what is in the mechanism and what is not— are fixed by reference to the phenomenon that the mechanism explains" [Craver (2007), p. 123]. A mechanism *of* certain phenomenon is composed of those entities, activities, and organizational features that are part of the system whose behaviour is the phenomenon of interest and are relevant for that phenomenon. A part is relevant for a phenomenon if it meets the requirement of mutual manipulability [Craver (2007)]. Therefore, a part X is a component of the mechanism *of* phenomenon Y if some interventions on X bring about changes in Y, and vice versa. Craver appeals to the notion of intervention developed by Woodward (2003). Woodward claims that "an intervention on some variable X with respect to some second variable Y is a causal process that changes the value of X in an appropriately exogenous way, so that if a change in the value of Y occurs, it occurs only in virtue of the change in the value of X" [Woodward (2003), p. 94]. Nevertheless, this proposal does not suit monetary transmission mechanisms. A monetary transmission mechanism is a mechanism of a phenomenon (i.e. the influence of a central bank in output, employment, prices, and inflation). But it is not composed of all entities, activities, and organizational features that are part of the system whose behaviour is the phenomenon of interest and are relevant for that phenomenon. Consider the South Korean monetary transmission mechanism. That mechanism is responsible for the influence of the Bank of Korea in the South Korean output, employment, prices, and inflation. Samsung Electronics, which is the largest South Korean firm, is part of the system whose behaviour is the phenomenon of interest (South Korea). It also meets the requirement of mutual manipulability and is relevant for the phenomenon. Some interventions on Samsung Electronics produce changes in the influence of the Bank of Korea in the South Korean economy, and vice versa. However, it is not part of the South Korean monetary transmission mechanism. In sum, MDC's proposal does not properly fix monetary transmission mechanisms' boundaries.[8]

MDC follow the extrapolation strategy for developing a general notion of mechanism. However, as it has been argued, their notion does not suit many kinds of mechanisms. It introduces certain requirements that are not met by those kinds of mechanisms. This also seems to be the case for the other proposals that follow the extrapolation strategy. For instance, Glennan's (2002) and Woodward's (2002) proposals do not suit neither economic mechanisms nor evolutionary mechanisms. They consider that properties of mechanisms' parts must remain stable in absence of interventions. However, properties of economic mechanism's parts (e.g. firms) and evolutionary mechanisms' parts (e.g. populations) may change even if no intervention has been done [Skipper and Millstein (2005)]. Consider the following hypothetical example of a firm. During a lunch at the office, there is a strong discussion between the CEO of firm X and the director of its department of publicity. As a consequence of this event, the CEO decreases the budget of the department of publicity. Due to the reduction of the budget, the department of publicity has to introduce changes in the advertising strategy of the firm (e.g. the number of ads on TV is decreased, while the number of ads on radio is increased). In this example, different properties of firm X (e.g. budget of its departments, number of ads on TV…) changed without any exogenous intervention.

IV.2. *The Difficulties of the Across-the-Sciences Strategy*

Illari and Williamson, who introduced the across-the-sciences strategy, follow it for developing a general notion of mechanism. Nevertheless, on my view they propose a vacuous and overly broad notion of mechanism. Illari and Williamson offer the following definition of mechanism:

> A mechanism for a phenomenon consists of entities and activities organized in such a way that they are responsible for the phenomenon. [Illari and Williamson (2012), p. 120]

A mechanism is an organized collection of entities and activities. No restrictions on regularity, internal structure, size, boundaries or robustness are imposed on them. Examples of entities are electrons, stars, black holes, x-rays… While examples of activities are colliding, relaxing, collapsing, radiating… Mechanisms' organization is merely defined as "whatever relations between the entities and activities discovered produce the phenomenon of interest" [Illari and Williamson (2012), p. 128]. There are several possible forms of organization (e.g. spatial, temporal, equilibrium, self-organization, feedback…). What forms of organization are relevant in a particular mechanism is an empirical question.

My main objection here is that Illari and Williamson's notion of mechanism is vacuous.[9] Their definition of mechanism relies on the concepts of entity, activity, organization, and being responsible for. Nevertheless, they do not properly characterize those concepts. For instance, consider the concept of entity. They offer neither a definition of entity nor a set of necessary conditions to be an entity nor a set of sufficient conditions to be an entity. Besides, they refuse to introduce restrictions on entities. They certainly present some examples of component entities of astrophysical and molecular mechanisms. Nevertheless, those examples are not numerous and diverse enough to properly characterize entities across the sciences. It could be argued that the concept of entity is too general, and a proper characterization of entities is not possible. However, other authors have already raised more concrete characterizations of component entities [see Machamer, Darden, and Craver (2000)]. Illari and Williamson's notion of mechanism is not precise enough. It is not clear what features would characterize mechanisms. They increase the scope of their notion of mechanism (i.e. the number of mechanisms that it subsumes) at the cost of decreasing its precision.

Another problem for Illari and Williamson's notion of mechanism is that it is overly broad. Although they consider that their characterization "is not so broad that it captures non-mechanisms" [Illari and Williamson (2012), p. 129], it subsumes things that could hardly be accepted as mechanisms. For instance, their notion would admit a group of cows grazing in a field as a mechanism. It is an organized collection of entities (e.g. cows) and activities (e.g. grazing) that are responsible for a phenomenon (i.e. the removal of the grass of the field). However, it could hardly be considered a proper mechanism. It is actually a mere aggregate, whose components are not actively organized [Craver and Darden (2013), p. 20]. Cows do not interact and make a difference to each other in order to remove the grass. Other examples of things that Illari and Williamson's notion would wrongly admit as mechanisms are a traffic jam and a group of babies napping.

The aim of Illari and Williamson is to develop a wide notion of mechanism that could encompass mechanisms of all fields. As it has been noted, they decrease the precision of their characterization in order to increase its scope. Nevertheless, Illari and Williamson's notion of mechanism does not suit many kinds of mechanisms. For instance, it would not fit evolutionary mechanisms. Illari and Williamson, as MDC, consider that mechanisms are collections of entities and activities. Hence, their notion of mechanism cannot account for those cases of evolution in which natural selection depends on passive selection processes that can hardly be considered activities. Their notion of mechanism would also be unable to account for economic mechanisms. Like MDC, they consider that a mechanism for a phenomenon is composed of those parts (e.g. entities, activities…) that are relevant for it. In this sense, they claim: "mechanisms are functionally individuated by their phenomena" [Illari and Williamson (2012), pp. 123-124]. But, as it has been argued, this idea does not suit economic mechanisms' (e.g. monetary transmission mechanisms) boundaries. In conclusion, despite of the fact that the across-the-sciences strategy is developed as an alternative to the extrapolation strategy, Illari and Williamson do not avoid the problem of the latter (see subsection IV.1).

Illari and Williamson follow the across-the-sciences strategy for developing a general notion of mechanism. Nevertheless, they do not satisfactorily achieve that purpose. The main problems of their notion of mechanism are that it is vacuous and overly broad. The other proposals that follow the across-the-sciences strategy seem to face the same kind of problems. For example, Glennan's (2017) recent proposal is overly broad too. It subsumes things that could hardly be accepted as mechanisms (e.g. a group of cows grazing, a traffic jam…). In addition, Glennan's notion is also unable to account for many kinds of mechanisms. As Illari and Williamson, he considers that mechanisms are collections of entities and activities, and that a mechanism for a phenomenon is composed of those parts that are relevant for it. Therefore, it does not suit evolutionary mechanisms and economic mechanisms either.

V. The Search for Generality and the Arguments in Support of the Mechanistic Approach

Mechanisms are relevant in several fields of science. In most of those fields (e.g. neuroscience, cognitive science, molecular biology…), a mechanistic stance has been adopted. From this fact, new mechanists have raised an argument in support of the mechanistic approach. They argue that the adoption of the mechanistic approach in a field of science would improve its relationship with the numerous fields in which this approach has already been adopted. Mechanisms would be the subject of study of all of them. The fields would only differ in which kind of mechanisms they study. Different fields of science would just study different parts of the hierarchy of mechanisms. In this sense, Craver and Alexandrova say that one reason why neuroeconomics should be a mechanistic science is that "the rest of neuroscience, cognitive science, and biology have adopted a largely mechanistic stance […] The search for mechanisms provides a common goal toward which researchers in different fields can contribute" [Craver and Alexandrova (2008), p. 398].

A related argument can be raised in favour of the mechanistic account of scientific explanation [Hedström and Ylikoski (2011)]. As it has been said (see section II), supporting a mechanistic account of scientific explanation is a trait of the new mechanism. New mechanists consider that a phenomenon is explained by means of specifying the mechanism that is responsible for it. The explanation of a phenomenon is often presented by means of a mechanistic model. A mechanistic model has two components: phenomenal description and mechanistic description [Glennan (2017), p. 66]. The phenomenal description is a model of the phenomenon and the mechanistic description is a model of the mechanism responsible for it. In a mechanistic model, the phenomenal description is (or represents) the *explanandum* and the mechanistic description is (or represents) the *explanans* [Glennan (2005), p. 448]. Due to the fact that mechanisms are relevant in several fields, new mechanists argue that a mechanistic account of scientific explanation could be adopted in most fields of science. Hence, it would be an all-encompassing account of scientific explanation. This can be presented as an argument in favour of it.

As it was pointed at the beginning of this paper, the mechanistic account of scientific explanation has been developed as an alternative to the covering-law model. A well-known problem of the covering-law model is that there are fields of science where only a few laws are known, such as evolutionary biology [see Beatty (1995); Scriven (1959)]. A nomological account of explanation can hardly be defended for those fields. Nevertheless, several mechanisms are often known in those fields where laws are not available. A mechanistic account of explanation could be adopted for them. The broad applicability of the mechanistic account of scientific explanation would be an argument to prefer it rather than other options.

Both previously presented arguments rely on the same assumption. They assume that the same notion of mechanism exists in all the fields where mechanisms are relevant. It is considered that the adoption of the mechanistic approach in various fields would improve the relationships among them because their subjects of study would be very similar. But they would be similar only if mechanisms are understood in a similar way in all fields. If those fields understood mechanisms in a very different way, the adoption of the mechanistic approach would not imply similar subjects of study. Likewise, it is considered that the mechanistic account of scientific explanation could offer a unified account of explanation because in several fields of science phenomena could be explained by means of referring to mechanisms. But it would be a unified standpoint only if mechanisms are similarly understood in all fields. If those fields understood mechanisms in a very different way, the mechanistic account of scientific explanation would not be unifier. Although several fields could refer to mechanisms, they would not refer to the same kind of things.

The assumption on which both arguments rely is challenged by the difficulties faced by the search for generality. It is considered that the same notion of mechanism is shared by all fields of science where mechanisms are relevant. The search for generality constitutes the real attempt of identifying that shared notion. New mechanists try to propose a notion of mechanism that suits most of the fields where mechanisms are relevant. Nevertheless, as it has been argued, both strategies for pursuing generality (i.e. the extrapolation strategy and the across-the-sciences strategy) face outstanding difficulties. This means that the assumption that the same notion of mechanism is shared by all fields is not justified and requires additional support. Not only is that shared notion unknown, but also several attempts of achieving it have failed. Therefore, both previously presented arguments in support of the mechanistic approach are not acceptable in their current form. They should not be used for endorsing the mechanistic approach.

VI. Conclusion

The search for generality is a general principle of the new mechanism. New mechanists consider that an appropriate notion of mechanism must be suitable for most of the fields of science where mechanisms are relevant. In order to propose a general notion of mechanism, two strategies have been adopted: the extrapolation strategy and the across-the-sciences strategy. As it has been argued, both of them face outstanding difficulties. The problems of the search for generality undermine some arguments in support of the mechanistic approach, which rely on the assumption that the same notion of mechanism exists in all fields where mechanisms are relevant.

It seems that current notions of mechanism are unable to properly account for all kinds of mechanisms. Moreover, it is doubtful that a general notion of mechanism could be developed. As Petri Ylikoski argues, "[t]he entities and processes studied by different sciences are quite heterogeneous, and it is probably impossible to propose a mechanism definition that would be both informative and cover all the prominent examples of mechanisms" [Ylikoski (2012), p. 22]. Giving this scenario, it would be advisable to abandon the search for generality. In each field of science, a notion of mechanism must be developed taking the activity of the scientists of that field as the main reference. How mechanisms are understood in other fields should not heavily influence in that development. It does not mean that philosophers of science must not think about similarities among mechanisms across the sciences. It could be very useful, after the development of the field-specific notions of mechanism, to compare the different notions of mechanism and identify their common features. Nevertheless, the output of that comparison would not be a proper notion of mechanism in general. In the same way that a list of the common features of English laboratories would not be a general definition of English laboratory. It would just be a list of traits that are shared by mechanisms across the sciences. It is an open question if, in spite of not being a definition, some of those shared traits may be necessary or sufficient conditions to be a mechanism. But that question exceeds the scope of this paper.

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NOTES

[1] Several classifications of the proposals raised within the new mechanical (or mechanistic) philosophy have been proposed [see Kuorikoski (2009); Reiss (2008)]. A particularly useful classification has been recently offered by Stuart

Glennan and Phyllis Illari (2018). They have distinguished two trends within the new mechanical philosophy: the new mechanism and the social scientific mechanism. In this paper, I will focus on what they call the new mechanism. It involves the senses of the term 'mechanism' that Holly Andersen (2014) has named as $mechanism_1$ and $mechanism_2$. The main ideas of the social scientific mechanism can be found in the works of Jon Elster (1989), (1999) and Peter Hedström (2005).

[2] There is a disagreement among new mechanists about whether mechanistic explanations are ontic (i.e. they explain because they fit the *explanandum* phenomenon into the causal structure of the world) or epistemic (i.e. they explain because they successfully increase our understanding of the world) [see Illari (2013)]. Nevertheless, all of them agree that mechanistic explanations refer to the mechanism responsible for the *explanandum* phenomenon.

[3] Bert Leuridan (2010) has claimed that mechanistic accounts are not genuine alternatives to nomologic accounts. Taking the pragmatic account of laws by Sandra Mitchell (1997) as his starting point, he argues that mechanistic models epistemologically depend on laws and cannot replace them as a model of explanation in science. However, Andersen (2011) shows that mechanistic models are not dependent on laws, but on regularities, which are not synonymous with laws.

[4] Peter Hedström [(2005), p. 25] has developed the application of MDC's notion of mechanism to sociology.

[5] Although Woodward is not properly a new mechanist, his work has strongly influenced many new mechanists [see Craver (2007); Glennan (2002); Woodward (2002), (2011)].

[6] Since the publication of Skipper and Millstein's paper, there has been a debate about how natural selection could be understood as a mechanism [see Barros (2008); DesAutels (2016); Illari and Williamson (2010); Pérez-González and Luque (2019)].

[7] Lane DesAutels (2016) has recently argued that natural selection is only irregular in aspects that are not relevant in order to meet MDC's requirement (e.g. product regularity, regularity regarding external sources of irregularity…).

[8] For other critiques against the mutual manipulability account of constitutive relevance see Leuridan (2012).

[9] Rosenberg (2018) has underlined the strategic vagueness of some mechanistic proposals. He claims that mechanists are often cagey in order to avoid counterexamples against their proposals.

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ORIGINAL PAPER

Evolutionary causes as mechanisms: a critical analysis

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Abstract In this paper, we address the question whether a mechanistic approach can account for evolutionary causes. The last decade has seen a major attempt to account for natural selection as a mechanism. Nevertheless, we stress the relevance of broadening the debate by including the other evolutionary causes inside the mechanistic approach, in order to be a legitimate conceptual framework on the same footing as other approaches to evolutionary theory. We analyse the current debate on natural selection as a mechanism, and extend it to the rest of the evolutionary causes. We focus on three approaches that we call the stochastic view, the functional view, and the minimalist view. We argue that all of them are unable to account for evolutionary causes as mechanisms. It is concluded that the current mechanistic proposals cannot be accepted as a common framework for evolutionary causes. Finally, we outline some guidelines and requirements that any mechanistic proposal should meet in order to be applied to evolutionary theory.

Keywords Mechanism · Natural selection · Evolutionary cause · Function · Stochastic

1 Introduction

Evolutionary biologists sometimes talk about evolutionary causes as mechanisms acting upon populations. For example, it is said that natural selection "is a powerful mechanism of evolution" (Herron and Freeman 2014, 227), that it "is an effective mechanism for producing adaptation" (Bell 2008, 499), but at the same time there

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are other “mechanisms [that] might overcome the limitations of natural selection” (Hamilton 2009, 368). Following this use, some philosophers have tried to develop a mechanistic approach for those causes, mainly focusing on natural selection. This could be a promising strategy for addressing some traditional topics in philosophy of biology. For instance, biologists and philosophers have argued for years on the (lack of) existence of biological laws and how this affects the scope of evolutionary explanations (Beatty 1995; Elgin 2006), since the traditional notion of scientific explanation (Hempel 1965) required laws as part of the *explanans*. The mechanistic account instead does not demand to appeal to laws in order to explain a phenomenon. It would also underline the link between evolutionary biology and other fields of science where the mechanistic approach is generally accepted (e.g. molecular biology).

Following the mechanistic approach to causal evolution, there has been a discussion about whether mechanistic proposals can account for evolutionary causes as mechanisms. This debate was introduced by Skipper and Millstein (2005), who claimed that the main notions of mechanism [those of Glennan (2002) and Machamer, Darden, and Craver (henceforth MDC) (2000)][1] did not suit natural selection. They identified three kinds of problems of those notions of mechanism in order to account for natural selection: problems related with parts or organization (i.e. their characterizations of mechanisms' parts or organization do not suit natural selection's parts or organization), problems related with productive relationships (i.e. they cannot account for some productive relationships that occur in natural selection), and problems related with regularity (i.e. natural selection does not meet MDC requirement of regularity).[2] Although Skipper and Millstein focused exclusively on natural selection, the same kind of problems would be found by Glennan's and MDC's proposals in order to account for other evolutionary causes (DesAutels 2018). For instance, evolutionary causes such as migration or genetic drift often depend on passive processes (e.g. lack of rainfall) that do not suit their accounts of productive relationships in mechanisms.

Our aim in this paper is to analyse current mechanistic approaches to causal evolution (those that have been developed after Skipper and Millstein's initial critique), which mainly focus on natural selection, and explore their validity for accounting for evolutionary causes. We argue that those approaches have to face important difficulties, and therefore in their current formulation are unsuitable for evolutionary theory. The structure of the paper is as follows. Section 2 presents the four main causes of evolution. Sections 3–5 analyse the three main current mechanistic approaches to

[1] These notions of mechanism, which were analysed by Skipper and Millstein, are ontic. They are based on the idea that mechanisms are part of reality and exist independently of us. However, Daniel J. Nicholson (2012) has proposed an epistemic notion of mechanism for biology and claimed that it can account for natural selection. Nicholson defines mechanisms as “epistemic models that enable the explanation of how phenomena are causally brought about” (Nicholson 2012, 161). Although Nicholson considers that his notion of mechanism allows us to understand natural selection as a mechanism, understanding natural selection (or another evolutionary cause) as a mechanism in this sense is problematic and does not suit biologists' ideas.

[2] Skipper and Millstein (2005) consider that only MDC's proposal faces problems related with regularity. Regarding Glennan's proposal, they argue that it “holds promise for capturing the way in which natural selection is regular” (Skipper and Millstein 2005, 342).

evolutionary causes. They respectively address what we call the "stochastic view", the "functional view", and the "minimalist view". We offer reasons why none of them can account neither for natural selection, nor for evolutionary causes in general. Finally, Sect. 6 concludes by underlying the potential benefits of the mechanistic proposal and noting some requirements that should be met by a mechanistic approach for evolutionary causes.

2 Evolutionary causes

Evolutionary theory usually establishes four main causes of evolution: mutation, migration, natural selection, and genetic drift.[3] Traditionally, the term mutation refers to an error in the replication of a nucleotide sequence. Nevertheless, currently "mutation" includes any alteration of the DNA molecule or any alteration of the genome such as inversions, deletions, translocations, duplications, etc. (Futuyma 2013). Migration refers to the movement of individuals between populations. These movements incorporate new genes to the gene pool of one population from one or other populations –technically, this incorporation is called gene flow, which requires not only migration but also mating in order to establish those new genes in the population (Conner and Hartl 2004). On the other hand, modern formulations of evolution by natural selection usually require three conditions: variation, heredity, and fitness differences. These are the so-called Lewontin's conditions for evolution by natural selection, heritable variation in fitness (Lewontin 1970). Although this formulation is not perfect (see Godfrey-Smith 2007), it is sufficiently general and used by researchers. Thus, we can use Lewtonin's conditions as a starting point. If in a population we have organisms that differ in their traits (variation), some of these organisms have more offspring than others due to these trait differences (fitness differences), and these traits are transmitted to the next generation (heredity), then evolution by natural selection occurs. Finally, allele and trait frequencies are also influenced by several factors that affect their trajectories in a stochastic way as a result of sampling process (Conner and Hartl 2004). This sort of randomness is called "genetic drift", an indiscriminate sampling process that produces specific effects on a population (Millstein 2002).

Unfortunately, there is no consensus among philosophers about how we should understand these different causes of evolution. Thus, a great number of different interpretations of causal evolution have been postulated: (1) the force interpretation, championed by Sober (1984); (2) the manipulationist approach based on the work of Woodward (2003) (see Reisman and Forber 2005; Shapiro and Sober 2007; Clatterbuck 2015); (3) the causal process approach, specially defended by Millstein (2006, 2013); (4) the counterfactual approach, developed by Glennan (2009) and Huneman (2012); (5) the probabilistic approach, elaborated in different ways by Abrams (2015), Razeto-Barry and Frick (2011), and Otsuka (2016); (6) and finally the mechanistic approach.

[3] There is disagreement among some philosophers on this causal view, arguing instead for a "statistical view" of evolution (Matthen and Ariew 2002, Walsh et al. 2002). In as much we accept that these phenomena are all causal, then we ask whether there can be a mechanistic account for them.

Until now, the mechanistic approach has mainly focused on natural selection (Barros 2008; DesAutels 2016; Illari and Williamson 2010). New mechanists have been arguing about how that approach suits natural selection, almost without devoting attention to the other evolutionary causes. However, the alternative approaches (e.g. the force interpretation, the counterfactual approach, etc.) aspire to locate the different evolutionary causes in a single framework. Thus, for example, the force interpretation conceptualizes the causes of evolution as forces, interacting analogously as Newtonian forces do in physical systems. This single framework aspiration results from the fact that biologists consider that all evolutionary causes are processes of the same kind (i.e. processes capable of producing changes in allele or trait frequencies, and whose (combined) effects are mathematically tractable), and that a common conceptual framework allows researchers to deal with those causes, their dynamics, and their relationships in a more effective way. Given this situation, we consider that the mechanistic approach must take on the challenge of conceptualizing all evolutionary causes as mechanisms, in order to be a legitimate conceptual framework on the same footing than the other approaches. In fact, the will of generality is already present in the new mechanistic philosophy itself (see Machamer et al. 2000; Illari and Williamson 2012; Glennan 2017). Moreover, Lane DesAutels (2018) has recently advocate the viability of the mechanistic approach as a common framework for some evolutionary causes –although this interesting first tentative does not address the issue in an extensive way. In what follows, we will analyse the current debate regarding the mechanistic interpretation of natural selection and extend it to all evolutionary causes. We will consider the main mechanistic proposals that have been developed after Skipper and Millstein's initial critique to the mechanistic approach.

3 Mechanistic proposals based on a stochastic view of mechanisms

After the initial critique by Skipper and Millstein on the mechanistic approach to natural selection, different kinds of mechanistic proposals have been raised. One sort of proposal is based on the idea that, due to the fact that natural selection is not regular, it could be possible to account for it as a mechanism by means of a notion of stochastic mechanism. This idea is proposed by Skipper and Millstein themselves after presenting their critique. In this sense, they said:

> In the context of natural selection, the most general statement we can make concerning directions for further work on the new mechanistic philosophy is this: to capture natural selection, a main evolutionary mechanism, a conception of stochastic mechanism as a non-unique causal chain is required in which change is produced by virtue of the ways in which property differences among members of a population in the context of some environment affect properties of that population. (Skipper and Millstein 2005, 345)

Barros (2008) has followed this advice and has developed a notion of stochastic mechanism in order to account for natural selection. Barros considers that by lowering the demands for regularity it is possible to understand natural selection as a mechanism in a sense close to that posed by Glennan and MDC. He defends that the regularity that must be demanded of a mechanism depends on the type of explanation in which it is integrated. He argues that "[t]he degree of regularity needed to make a satisfactory scientific explanation depends in part on whether the explanation is being made ex post or ex ante" (Barros 2008, 309). He divides mechanistic explanations between ex post, which just explain the occurrence of a phenomenon after its occurrence, and ex ante, which "seek to explain both how a phenomenon has occurred in the past and to predict how it will occur in the future" (Barros 2008, 309). Barros claims that ex post explanations are always deterministic and make reference only to deterministic mechanisms. However, within ex ante explanations, he distinguishes between deterministic and stochastic explanations, depending on what kinds of predictions they support. Ex ante deterministic explanations are ex ante explanations which appeal to a deterministic mechanism and which support predictions with certainty. Ex ante stochastic explanations are ex ante explanations which appeal to a stochastic mechanism and where the "outcome can be predicted in advance in terms that are probabilistic" (Barros 2008, 311). Stochastic mechanisms can be biased, if they give the result a probability greater than 50%, or unbiased, if they give the result a probability equal to or less than 50%. It would be possible to distinguish between ex ante biased stochastic explanations and ex ante unbiased stochastic explanations. Natural selection would be a biased stochastic mechanism and would be involved in ex ante biased stochastic explanations. As a biased stochastic mechanism, which is present in ex ante biased stochastic explanations, natural selection just has to work more than half of the time in the same way under the same conditions.

The main problematic aspect of Barros' proposal is the idea that populations are component entities of natural selection. Barros considers that natural selection is a two-level mechanism. In order to understand natural selection in mechanistic terms it is necessary to appeal to both individual level and population level mechanisms. At the population level, natural selection is a mechanism that has populations as components. Barros understands a population as "an abstract entity that describes a group of individual organisms" (Barros 2008, 316). Understanding natural selection as a mechanism whose component entities are populations gives rise to different problems. Firstly, it would produce an identification between the subject of the overall phenomenon of the mechanism and the components of the mechanism. The mechanism would connect initial population-level conditions with final population-level conditions, through different states at the population level. This goes against the idea, which underlies the mechanistic approach, that a mechanism builds a link between a phenomenon of certain level and lower-level entities and activities (Machamer et al. 2000, 19). Presenting a mechanism means to open a black-box (a connection between an input and an output whose structure is considered inexistent or irrelevant) and the aim of a mechanism is to provide "a fine-grained as well as tight coupling" (Hedström and Swedberg 1998, 25) between the input and the output. Actually, a population-level mechanism of natural selection would not be a mechanism, but a succession of causal relations at a certain fixed level.

Secondly, it would mean accepting that a real concrete system can be entirely composed of abstract entities and their relations. We can divide the notions of mechanism between ontic notions, which consider that mechanisms are concrete things in the real world and exist independently of us, and epistemic notions, which consider that mechanisms are pieces of scientific reasoning. Barros is aligned, like Glennan and MDC, with the ontic conception of mechanisms and considers that mechanisms are concrete things. His idea that a mechanism could be composed of populations, which he defines as abstract entities, and their relations implies assuming that a real concrete system could be entirely composed of abstract entities and their relations. It would create several problems regarding mechanisms' ontological status.

It could be though that a different notion of stochastic mechanism, which eludes the diverse problems of Barros' proposal,[4] could correctly account for natural selection and the other evolutionary causes. However, it is not at all clear if it is the case. Every attempt at understanding evolutionary causes as mechanisms by means of a notion of stochastic mechanism would be built on the assumption that they are stochastic, but we consider that this idea could be problematic too. Certainly, genetic drift is traditionally portrayed as a stochastic factor of evolution, producing unpredictable fluctuations in allele frequency (Gillespie 2004; Rice 2004). However, the stochastic character of other evolutionary causes such as natural selection, migration or mutation is at least dubious.

Several authors in this debate (Barros, Skipper, Millstein…) have accepted the stochastic nature of natural selection. However, we think that defenders of the mechanistic view should consider that the stochastic character of natural selection and other evolutionary causes is not sufficiently supported, especially from the mathematical apparatus of Population Genetics. Population Genetics textbooks usually start formulating the Hardy–Weinberg law. This law assumes: random mating, discrete generations, no mutation, no migration, no random genetic drift (infinite population size), and no natural selection. Therefore, by relaxing these assumptions we can elaborate dynamic models in order to predict the allele frequencies provided that one or more evolutionary causes are acting on populations. For differences in fitness –natural selection– one of the simplest examples is one locus with two alleles, A and a, with frequency p and q (respectively), non-overlapping generations, and with constant genotypic fitnesses w_{AA}, w_{Aa}, w_{aa}. The model deals with viability selection, where w is the average probability of survival from zygote to reproductive age. Assuming Hardy–Weinberg equilibrium before selection, the frequency of A in the next generation is

$$p' = \frac{w_{AA}p^2 + w_{Aa}pq}{\bar{w}}$$

where $\bar{w}$ is the mean population fitness $(w_{AA}p^2 + 2w_{Aa}pq + w_{aa}q^2)$. The expected change in the frequency of A is

[4] Joyce C. Havstad (2011) has also raised some other problems of Barros' proposal. She noted that the model of the mechanism of generalized natural selection proposed by Barros is too general and due to this fact is unable to distinctively characterize natural selection. The model proposed by Barros is not a model of generalized natural selection but a model of selection in general, which fits any selective process.

$$\Delta_p = p' - p = p\left(p\frac{w_{AA}}{\bar{w}} + q\frac{w_{Aa}}{\bar{w}} - 1\right)$$

We can reduce the portion of the brackets as

$$\Delta_p = p\left(\frac{w^* - \bar{w}}{\bar{w}}\right)$$

where w^* is the marginal fitness of allele A, i.e., a measure of its average fitness, taking into account the frequencies of the other alleles present in the genotypes in which A is present (Charlesworth and Charlesworth 2010). This model of natural selection is a deterministic one. That is, the changes in allele frequencies must be viewed as part of a deterministic process. Although this is one of the simplest models, it shows that natural selection is modelled deterministically in Population Genetics. This is also the case for migration and mutation. Mutation is introduced by specifying the rate at which each allele (A and a) mutates to the other. In the same way, migration is introduced by specifying the rate at which a proportion of individuals immigrates or emigrates. Thus, we can combine all these different evolutionary causes, elaborating more deterministic models. For example, the *mutation-selection equilibrium* model

$$\hat{p} = \sqrt{\frac{\mu}{s}}$$

where μ is the mutation rate and s is the strength of selection, shows how the action of natural selection against a deleterious allele is compensated by a high mutation rate of change from the normal allele to the deleterious, the population being in equilibrium (Rice 2004). Similarly, the effects of selection and migration can be represented as

$$\Delta p_1 = \frac{p_1}{\bar{w}} a_A - m\left(p_1 - p_2\right)$$

where p_1 and p_2 are the frequency of the allele in each population, a_A is the average excess of fitness of the allele A, and m is the migration rate (Templeton 2006). However, when drift is introduced, the effects of these evolutionary causes are represented as a stochastic model calculating the probability distribution of populations. Thus, for the equilibrium probability distribution of allele frequency under selection, mutation, migration, and drift we obtain

$$\hat{\Psi} = C\bar{w}^{2N_e}(1-p)^{4N_e(u_1+m-mp_I)-1} p^{4N_e(u_2+mp_I)-1}$$

where C is a constant, and N_e the effective population size, u is the mutation rate, and mp_I is the migration rate times the frequency of the allele A among immigrants (Rice 2004). This is standard in any Population Genetics textbook (Charlesworth and Charlesworth 2010; Ewens 2004; Rice 2004). We start with a deterministic theory, which includes models of selection, mutation, and migration. Thereafter, we construct a stochastic theory including random genetic drift by postulating a finite population size, and now evolution is considered as a stochastic process, where deterministic models are replaced by stochastic models, like Markov chain theory and Diffusion theory, combining deterministic and stochastic processes.

Certainly, it could be argued that the fact that some evolutionary causes (natural selection, migration, and mutation) are modelled deterministically in Population Genetics does not refute by itself their stochastic interpretation. That deterministic character could be an idealizing assumption of the models that belies biological reality. Furthermore, not every theoretical work models those evolutionary causes in a deterministic way.[5] As Millstein et al. (2009) claim, although mathematical models are relevant for understanding biological concepts, "models themselves are not the ultimate resource" (Millstein et al. 2009, 6). In order to accurately understand evolutionary causes is necessary to also take into account the historical and contemporary biological practice. Nevertheless, we consider that biological practice also casts doubt on the stochastic interpretation of some evolutionary causes. When biologists deal with real populations in their day-to-day practice, they often understand evolutionary causes such as natural selection, migration, and mutation in a deterministic way. They consider that those causes are deterministic processes that influence the change in trait frequencies, and that the stochasticity of populations' evolutionary path is mainly a product of genetic drift. In this sense, evolutionary biologist Graham Bell says: "Drift and selection are not alternatives. All populations are finite, and few are completely devoid of variation in fitness, so both drift and selection will almost always occur together. The most important effect of drift is that it makes the outcome of selection less predictable. The expected response to selection per generation in a finite population is $sp(1-p)$, its deterministic value, but through sampling error it will deviate from this precise value, the variance of this deviation being $p(1-p)/N$" (Bell 2008, 69).[6] Actually, this deterministic conceptualization[7] was already present in some classical works regarding evolutionary theory. For example,

[5] There are some theoretical works where multiple evolutionary causes, and not only genetic drift, are modelled stochastically. For example, Rice and collaborators (Rice 2008; Rice and Papadopoulos 2009; Rice et al. 2011) have developed a stochastic version of the Price equation that can deal with random variables as stochastic fitness and stochastic migration, and therefore allowing to model selection and migration as stochastic processes. However, we consider that those theoretical works do not accurately represent biologists' ideas about the nature of evolutionary causes. Biologists often understand evolutionary causes other than drift as deterministic processes. From our point of view, modelling stochastically those evolutionary causes is probably just a result of epistemological limitations. This seems the case of Rice and collaborators, inasmuch they talk repeatedly about our epistemic problems to study evolutionary systems and the necessity to construct stochastic models to supply those shortcomings. For example, they say that "we can not know with certainty how many descendants an individual will leave or what they will look like until after reproduction has taken place" (Rice and Papadopoulos 2009, 2); and that "[b]ecause we can not know with certainty how many descendants each individual in a population will have, we need to treat fitness as a random variable -having a distribution of possible values" (Rice et al. 2011).

[6] It is necessary to point out that we are not claiming that any deviation from fitness expectations should be attributed to drift. That deviation could be the result of other elements (selective pressures and/or other evolutionary causes that were not taken into account, a spurious statistical correlation, etc.).

[7] Another remarkable example of this deterministic conceptualization is provided by Brian Charlesworth: "In the era of multi-species comparisons of genome sequences and genome-wide surveys of DNA sequence variability, there is more need than ever before to understand the evolutionary role of genetic

in the well-known experiment by Dobzhansky and Pavlovsky (1957), it is argued that the apparent stochasticity of natural selection is a consequence of the finite size of populations (i.e. genetic drift). Dobzhansky and Pavlovsky tracked the frequencies of two genetic types, PP and AR, which are different inversions on the third chromosome in *Drosophila pseudoobscura*. They replicated twenty populations, ten with a large initial population (of about 4000 flies) and ten with a small initial population (of about 20 flies). They found that the outcome of natural selection in the studied populations was conditioned by genetic drift. Although, "the environments being reasonably uniform in all experimental populations, the outcome of the selection processes in the replicate experiments should also be uniform" (Dobzhansky and Pavlovsky 1957, 316), the finite size of the populations (i.e. genetic drift) prevent the outcomes from being uniform. They also showed that, as the population size decreases and the influence of genetic drift increases, the deviations become greater, increasing the fluctuations across generations.

Defenders of the stochastic view of evolutionary causes could argue, as Skipper and Millstein (2005) do regarding natural selection, that several identical real populations under the influence of the same evolutionary cause would, in all likelihood, differ in their evolutionary outcomes. The structure of the argument would be as follows. Imagine that we have one hundred populations of an organism (like finches), with the same population size, the same distribution of beak lengths, and all located in the same environment, and that one evolutionary cause such as natural selection, mutation, or migration acts upon them. It would be expected that, despite the fact that the evolutionary cause is equally acting in all of them, the evolutionary outcomes of the various populations would not be equal (i.e. the distribution of break lengths in the next generation will differ). It could seem that this kind of argument supports the idea that those evolutionary causes are stochastic processes whose outcomes are not fully predictable. However, we think that it is inaccurate. From biologists' point of view, that difference in populations' outcomes would not be a consequence of the stochastic nature of those evolutionary causes, but an effect of genetic drift (Hansen 2017). The populations' evolutionary outcomes would differ just because, since those populations are finite, genetic drift affects them.

On balance, to claim that natural selection and other evolutionary causes such as migration and mutation are stochastic processes needs more support and deal with the theoretical mathematical models developed in the last century. The stochastic view, in order to become a common framework and account for evolutionary causes as stochastic mechanisms, requires conceptualizing evolutionary causes as stochastic processes. A process can only be understood as a stochastic mechanism if it is stochastic. Although some evolutionary causes –like genetic drift– fit into that framework, others –like migration or natural selection– are less clear. Therefore, we argue that both parts, defenders and critics of the mechanistic approach, must do not take for granted the stochastic nature of some evolutionary causes and

Footnote 7 (continued)
drift, and its interactions with the deterministic forces of mutation, migration, recombination and selection." (Charlesworth 2009, 195).

discuss more deeply on it. This also undermines Skipper and Millstein's argument that natural selection is not regular enough and does not meet MDC's requirement of regularity. Their critique, which motivates Barros' proposal, is not justified enough. Although this gives new chances for the mechanistic approach, it still has to handle with other evolutionary causes (essentially, genetic drift) that are unquestionably considered stochastic. A defender of the mechanistic view could answer that it is possible, as Barros shows, to hold a pluralistic mechanistic framework and consider that mechanisms could be deterministic or stochastic. Following this line of argumentation, it could be argued that all evolutionary causes are mechanisms, although some are deterministic mechanisms and other are stochastic mechanisms. However, if this position was taken, the question would be whether in that scenario evolutionary causes would actually be allocated in a single framework. There would be some relevant differences among them (e.g. grade of regularity, type of connection among its components, predictability, etc.), and it is not clear which similarities would be underlined by this framework.

4 Mechanistic proposals based on a functional view of mechanisms

There is a strong connection between the notion of mechanism and the notion of function. Several definitions of mechanism have been elaborated on the basis that a mechanism is something that performs a function. The most relevant of them is the notion of mechanism proposed by Bechtel and Abrahamsen (2005). They define a mechanism as a "structure performing a function in virtue of its component parts, component operations, and their organization" (Bechtel and Abrahamsen 2005, 423). More recently, Garson (2013) has also defended a functional notion of mechanism.

Recently some authors have tried, inspired by functional notions of mechanism and based on the consideration that natural selection performs a function, to respond to the Skipper and Millstein's initial critique and defend the possibility of understanding natural selection as an MDC mechanism. Illari and Williamson (2010) have argued that natural selection is decomposable into parts (entities and activities) and has organization. In a similar line of argumentation, Lane DesAutels (2016) has argued that natural selection meets the requirement of regularity imposed by MDC.

Illari and Williamson argue that for a complex system to be a mechanism it has to perform a function. In this sense they affirm: "mechanisms are mechanisms for a phenomenon. In that sense, mechanisms have functions" (Illari and Williamson 2010, 283). If the mechanism is integrated into a system, "function" must be understood as "causal-role" function (Cummins 1975). If the mechanism does not refer to a system that integrates it, then "function" has to be understood on the basis of the notion of Craver (2001) of "isolated description". In the case of natural selection, they consider that it does not refer to a system that integrates it and "function" must be understood on the basis of the notion of "isolated description".

Craver (2001) considers that there are three ways to describe the activity of a mechanism: contextual description, isolated description, and constitutive description. Isolated description consists of describing the activity of the mechanism regardless of context (Craver 2001, 64). From this perspective the activity of the mechanism: (1) does not refer to a context, (2) does not refer to objects beyond the limits of the mechanism, (3) it is something that the mechanism produces by itself, and (4) allows setting the active, spatial and temporal limits of the mechanism. Illari and Williamson appeal to a notion of function derived from this type of description. According to this notion, which is not made explicit by Craver, the function of a mechanism is the activity assigned to it by means of an isolated description. They refer to this activity as the "characteristic activity" of the mechanism. From this approach the function of the heart would be to contract. In the case of natural selection, they consider that its function –characteristic activity—is the production of adaptations.

Illari and Williamson argue that by taking the function of a mechanism as a reference it is possible to decompose it into entities and activities. They consider that the components of a mechanism have to be identified and individualized on the basis of their functions. In this sense they say: "successful structural decomposition is into functionally relevant parts" (Illari and Williamson 2010, 284). In relation to the components of the mechanisms "function" must be understood as a "causal-role" function. Regarding the function of the entities they affirm: "The function of an entity is the role it plays in the overall behaviour of the mechanism" (Illari and Williamson 2010, 285). Besides, regarding the activities, they maintain a similar position and affirm: "[a]ctivities are individuated in a similar way to entities in the hierarchy of mechanisms. Activities are identified in terms of their contribution to the behaviour of the phenomenon to be explained" (Illari and Williamson 2010, 285). The function of a component is always dependent on the function of the mechanism, since the function of the component is characterized on the basis of its contribution to the function of the mechanism. Therefore, since the individualization of the components depends on their function, the individualization of the components depends on the function of the mechanism.

They consider that insofar as natural selection has a function, it is decomposable into parts. In the case of natural selection, the components would be sub-mechanisms that are integrated into it and contribute to its function. Examples of such component entities of natural selection would be populations, organisms, cells, etc. Examples of activities would be reproduction, recombination, and so on.

Illari and Williamson also defend that by taking as a reference the function of a mechanism it is possible to attribute organization to it. They define the organization of a mechanism as "whatever features exist by which the activities and entities each do something and do something together to produce the phenomenon" (Illari and Williamson 2010, 289). The organization can be of different types: spatiotemporal organization, feedback, control systems, part-whole, etc. They consider that natural selection, insofar as it has a function, is an organized mechanism. With regard to the type of organization that occurs in natural selection, they point out that "no one form of organization is present in all cases of natural selection but only organization understood at a certain level of abstraction" (Illari and Williamson 2010, 290). However, with regard to the concrete cases of natural selection they affirm: "natural selection in the concrete case does show spatiotemporal organization" (Illari and Williamson 2010, 290).

DesAutels takes as his starting point the thesis defended by Illari and Williamson. His argument assumes the following considerations: (1) mechanisms have a function, (2) natural selection has a function (to produce adaptation), and (3) natural selection is decomposable into entities and activities. On the basis of these considerations he argues "natural selection only fails to be regular in ways that are unthreatening to its status as MDC mechanism" (DesAutels 2016, 16). Firstly, DesAutels considers that the regularity demanded can be understood as process regularity or as product regularity. The process regularity consists in that "the constituent entities and activities of a mechanism behave in roughly the same way each time the mechanism operates" (DesAutels 2016, 16) and product regularity consists in that "the output of a mechanism is roughly the same" (DesAutels 2016, 16). He considers that the relevant regularity to be an MDC mechanism must be the process regularity, due to the fact that the paradigmatic example of an MDC mechanism (protein synthesis) is process regular but not product regular. Natural selection is not product regular, as noted by Skipper and Millstein (2005, 343). However, natural selection is process regular.

Secondly, DesAutels distinguishes between internal and external sources of irregularity. The irregularity of a mechanism may be due to elements internal to it or elements external to it. The delimitation of a mechanism (to establish what is internal and what is external to it) depends on its function. In this respect he says: "entities and activities are constitutive of a given mechanism just in case the mechanism could not serve its function without them" (DesAutels 2016, 18). In order to be an MDC mechanism the relevant aspect is not to be irregular due to internal sources. The criterion for being regular cannot be regularity regarding external sources because even the most regular mechanisms (e.g. synaptic transmission, protein synthesis, DNA replication, etc.) may be affected by external sources of irregularity.[8] Skipper and Millstein (2005, 343) reveal the irregularity of natural selection over external sources of regularity, but not over internal sources.[9]

The authors whose proposal is based on a functional view of mechanisms consider that natural selection has a primary function: producing adaptations. As we have seen, this idea is the cornerstone of their approach and all their arguments ultimately rely on it. Nevertheless, we consider that producing adaptations is not the function of natural selection. Illari and Williamson say: "Natural selection having an isolated description is no problem. Natural selection explains adaptation, because natural selection characteristically produces adaptation. So natural selection is a mechanism *for* adaptation" (2010, 283). DesAutels agrees: "Quite clearly,

[8] We think that, in the case of natural selection, those external sources of irregularity identified by DesAutels –i.e. "non-critical environmental features which are not constitutive of the token mechanism [selection]" (2016, 19)– are very likely to be just instantiations of drift processes.

[9] DesAutels also proposed a third distinction. He distinguishes between abstract and concrete regularity. Abstract regularity is the ability of a type mechanism to subsume different token mechanisms. On the other hand, concrete regularity is the capacity of a type mechanism to give a detailed account of the token mechanisms that it subsumes.

natural selection is a system *for* something: it is that which brings about adaptation" (2016, 14). This move is quite natural. Organisms appear to be designed for their environments. This apparent design, attributed to a supernatural designer for centuries, needed a naturalistic explanation. Darwin gave us that naturalistic explanation where the process of natural selection progressively improves organism's suitability to their environment, and therefore giving them the appearance of design. Since Darwin published his theory, natural selection has been strongly connected to the concept of adaptation. Nevertheless, our aim in this part of the section is to challenge this deep connection, and thus partially undermining the functional argument of natural selection as a mechanism for adaptation.

The original formulation of natural selection by Darwin was strongly influenced by William Paley's "argument from design" (Darwin 1958; Ayala 2004) and the demographic works of Robert Malthus (Darwin 1958; Eldredge 2005). Thus, Darwin focused on explaining how highly functional organs like the human eye (Paley) could have emerged from the struggle for existence. This struggle would be an ineludible result of lack of resources in nature due to the geometrical growth of populations (Malthus). Following this line of argumentation, some authors (for instance Dennett 1995) proposed to define fitness as an individual's capacity to solve "design-problems" set by the environment, i.e. its capacity to fit in that environment. This engineering approach has been very successful in some areas (like behavioral ecology), and especially in popular explanations of the theory of natural selection. This engineering view is based on the idea that organisms evolve traits that maximize the ability of a population of those organisms to increase in size, i.e. traits that increase overall population growth rate (Rice 2004).

However, theoretical and experimental advances over the last century show a subtle but critical distinction between the efficiency of an individual and its capacity to fit or adjust in a particular environment, i.e. to solve the "design-problems". Imagine a female lion –a type of lion– with the best possible characteristics to deal with all the challenges of its environment: a short, thin coat to carry high temperatures; a strong and robust body structure capable of dealing with all kinds of blows, falls, and collisions; sharp fangs to tear flesh; strong claws to catch prey; sexually attractive to seduce male lions; etc. This (type of) lion is perfectly adapted to its environment. Nevertheless, imagine that this (type of) lion is sterile. If that is so, then its fitness (i.e. its reproductive efficacy) would be null because it does not leave offspring and therefore its genes do not pass to the next generation. Natural selection would act against this type of lions –against the infertile trait–, although their suitability to the environment is impressive.[10] It is necessary to understand that, ultimately, natural selection acts on one trait –fitness, i.e. reproductive success– and it may act indirectly on other traits.[11] The idea is that natural selection does not necessarily

[10] Certainly, there are examples of sterile organisms with positive fitness, like in eusocial insect colonies, where some individuals forego their reproductive capacity in order to support the reproduction of their relatives. These types of organisms successfully pass their genes to the next generation. In our example, there is no such behavior.

[11] As Gillespie says: "To a geneticist, fitness is just another trait with a genetic component. To an evolutionist, it is the ultimate trait because it is the one upon which natural selection acts" (Gillespie 2004, 59).

lead to adaptation, as Darwin thought, but always leads to non-random reproductive success.[12] That is, adaptation is a potential (but not necessary) outcome of the process of natural selection (Gould and Lloyd 1999). Here is an example by Richard Lewontin:

> A mutation that doubled the egg-laying rate in an insect, limited by the amount of food available to the immature stages, would be very rapidly spread through the population. Yet, the end result would be a population with the same adult density as before but twice the density of early immatures and much greater competition among larvae stages. Periodic server shortages of food would make the probability of extinction of the population greater than it was when larvae competition was less. Moreover, predators may switch their search images to the larvae of this species now that they are more abundant, and epidemic diseases may more easily spread. It would be difficult to say precisely what environmental problem the increase of fecundity was a solution to. (Levins and Lewontin 1985, 81)

Those mutant insects mentioned by Lewontin are not better adapted because there is no improvement in their performance regarding environmental challenges. That is, there is no better fit to their environment because they have double offspring but also double mortality. Now imagine that some of those mutant insects suffer another mutation that doubled the efficiency for metabolizing food. That would be an adaptive improvement and it would be reflected in the population census, increasing the population size. This is what Darwin had in mind and why the term *fitness* was used, since *to fit* makes reference to the grade of adaptedness of an individual to its environment. In other words, natural selection does not necessarily optimize any individual trait—i.e. an optimal trait value that maximizes the fitness associated with that trait–, and when it does it is under rare circumstances such as when the trait has no phenotypic variance at equilibrium, and there is nonlinearity between the trait and fitness at equilibrium (see Crow and Nagylaki 1976; Templeton 2006, for mathematical details).

In summary: "The point here is that the dynamics of selection depend on the dynamics of population growth, and this critically affects the outcome of selection. Survival of the fittest is just one of many possible outcomes. There is more to selection and evolutionary success that increase of the better-designed phenotypes" (Michod 1999, 27). Of course, there are in the literature definitions of adaptation where the most adapted phenotype is always chosen by natural selection (see Reeve and Sherman 1993). Nevertheless, we think that they are misleading, since there are conditions where natural selection operates and the best-adapted organisms do not succeed.[13] Therefore, one might say that that undermines the functional argument

[12] De Jong endorses a similar claim: "Differences in adaptation will lead to fitness differences, but fitness differences are not necessarily associated with differences in adaptation" (De Jong 1994, 20).

[13] Another example of this is a particular type of selection, the so-called called "survival of the first", where a best adapted type cannot invade a population because the population growth is superexponential (see Michod 1999, chap. 3; Nowak 2006, chap. 2, for mathematical details). It could be argued that the fact that natural selection does not always produce adaptation, does not imply that adaptation is not the

of natural selection as a mechanism for adaptation. In our opinion it is true that a mechanism always needs the same function, but it certainly isn't true that if there is a different function, there is no mechanism. We have tried to show that the function of natural selection is not what Illari, Williamson and DesAutels thought it was, but this is quite different to there not being any function at all. It could be argued that the proper function of natural selection is to increase the reproductive success. However, this change has a cost for the functional view, because changing the function implies changes in the entities and activities that compose the mechanism, as well as its organization and boundaries, inasmuch all those elements rely upon the assumed function of the mechanism.

Illari and Williamson—and DesAutels to the extent that he probably follows them in this aspect–, are not only wrong when they claim that the function of natural selection is the production of adaptation, they are also wrong when they consider that, if we defined the function of a mechanism as the activity assigned to it by means of an isolated description (characteristic activity), then the function of natural selection would be the production of adaptation. Often, when an isolated description of a process of natural selection is presented, the activity assigned to it is not the production of adaptation, but the increase of reproductive success.

The functional view, in order to be applied to evolutionary causes, needs to assign functions to them. The problem is that each evolutionary cause brings about several outcomes and it is difficult to identify one of them as its function. Mutation is usually considered the ultimate source of genetic variation. So, a defender of the functional view may claim that the function of mutation is to provide genetic variation. However, a crucial problem arises very quickly when we try to assign functionality to particular outcomes of migration and drift: there are too many. Migration and drift have several impacts on populations. Migration introduces genetic variation in a population. It also reduces the level of differentiation among populations, homogenizing the populations of a species. In addition, migration is crucial for hybridization and for the process of speciation. Meanwhile, drift plays a major role in the survival of new mutations and their possible fixation in a population. It removes genetic variation in a population, but at the same time increases the level of differentiation among populations. It also, as a random process, affects the predictability of a population. In addition, it should be recalled that all evolutionary causes affect gene frequencies (another outcome). Therefore, migration and drift produce several outcomes upon populations, and this is also true for mutation and selection. Mutation alters the change in gene frequency, but also increase variation within subpopulations and decreases the variation among subpopulations. Likewise, natural

Footnote 13 (continued)
function of natural selection. In order for a mechanism to have a function it does not have to always succeed at implementing that function. For example, heart's function is to pump blood at a specific rate, but sometimes it does not pump blood at that rate. Nevertheless, it does not seem the case for natural selection and adaptation. When a heart does not pump blood at a proper rate, doctors consider that it is not producing its function in a correct matter. However, when natural selection is acting but it does not produce adaptation, evolutionary biologists do not consider that it is not producing its function in a correct matter, as long as there is non-random differential reproductive success.

selection alters the variation within and among subpopulations, as well as changing the gene frequencies. Thus, the functional view must contend with the problem of attributing a particular function for each evolutionary cause in spite of the great variability of outcomes. This problem could not be resolved by means of considering that the function of an evolutionary cause is its characteristic activity (i.e. the activity assigned to it by means of an isolated description), because the production of all the outcomes noted above is assigned to the causes precisely when they are described in isolation.

The fact that several phenomena or outcomes are attributed to each evolutionary cause is also problematic for the functional view in another related sense. A mechanism is always a mechanism for some phenomenon (Glennan 1996, 52; Bechtel and Abrahamsen 2005, 422; Craver 2007, 123). The defenders of the functional view consider that the identification and delimitation of a mechanism depends on the phenomenon for which it is responsible. A mechanism is composed of those entities, activities, and organizational features that contribute to the phenomenon for which it is responsible. It implies that the mechanism responsible for each phenomenon or output is different. Hence, from their proposal, the mechanism responsible for each outcome attributed to a particular evolutionary cause would be a different one. But it does not suit evolutionary biologist ideas. They consider that the *same* particular evolutionary process is responsible for all those outputs. Figure 1 shows a particular model of migration, a circular stepping-stone model, where migration occurs only between adjacent demes. In this case, the entities and activities that contribute to each output attributed to a particular case of migration are not the same. Therefore,

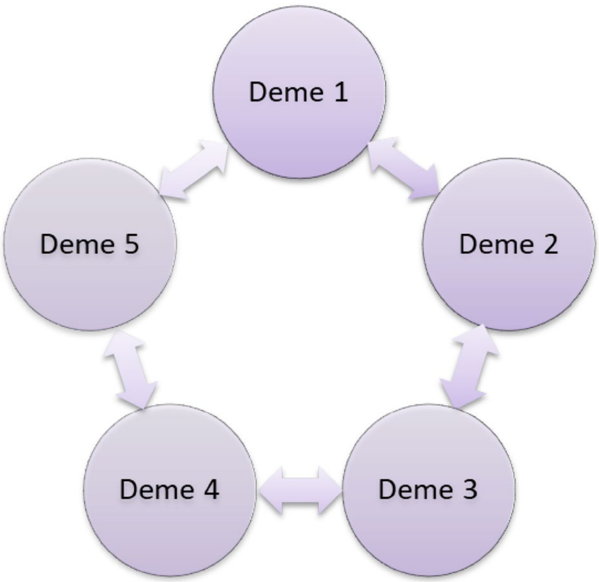

Fig. 1 This image represents a circular stepping-stone model, where migration occurs only between adjacent demes. A particular phenomenon of migration generates two different outcomes (i.e. changes in two demes). The entities and activities responsible for those outcomes are not exactly the same

from the functional approach's point of view, the mechanism responsible for each outcome would be different. On the contrary, evolutionary biologists consider just one evolutionary cause for all outputs attributed to a particular case of migration.

In order to avoid those problems, the defenders of the functional view could answer that the phenomenon for which a particular evolutionary mechanism is responsible is the conjunction of the outputs attributed to it by biologists. In that case, the mechanism would be composed of every entity, activity, and organizational feature that contribute to any of that outcomes. However, this approach does not suit biologists' ideas and in our view it seems an artificial and ad hoc construction. Biologists consider those outcomes as different phenomena produced by the same cause, not as parts of the same phenomenon.

5 Mechanistic proposals based on a minimalist view of mechanisms

Glennan (2017) has recently adopted a new approach in order to account for the diverse kinds of mechanisms (including evolutionary mechanisms). He has assumed a minimalist view. Glennan has abandoned his previous notion of mechanism (see Glennan 1996, 2002) and developed a minimal characterization which aims to be "broad enough to capture most of the wide range of things scientists have called mechanisms" (Glennan 2017, 18). Thus, he defines a mechanism for a phenomenon as follows:

> A mechanism for a phenomenon consists of entities (or parts) whose activities and interactions are organized so as to be responsible for the phenomenon. (Glennan 2017, 17)

Glennan considers that a mechanism is composed of organised entities and their activities. Entities are "objects—things that have reasonably stable properties and boundaries" (Glennan 2017, 20) while activities are "a kind of process—essentially involving change through time" (Glennan 2017, 20). Activities that involve more than one entity (pushing, eating, hitting…) are called interactions. Regarding mechanisms' organization, Glennan considers that it has a horizontal dimension (i.e. spatio-temporal and causal organization among the mechanism's components) and a vertical dimension (i.e. relation between the mechanism as a whole and its component activities).

Although Glennan's new minimal notion of mechanism aims to account for mechanisms across the sciences, it does not suit evolutionary mechanisms. Glennan considers mechanisms in general and his notion include general characteristics that are often present in mechanisms. Nevertheless, his proposal does not take into account the specific traits of evolutionary causes. In fact, this new version of Glennan's proposal faces the same kinds of problems (i.e. problems related with parts or organization, and problems related with productive relationships) that the previous version of it (see Sect. 1). In the first place, Glennan's notion of mechanism's component entity (or part) does not suit evolutionary causes' parts. Glennan characterizes mechanisms' component entities as "stable bearers of causal powers" (Glennan 2017, 35). He considers that entities must have reasonable stable properties and boundaries. The stability required to entities depends on the mechanism in which they are involved. A component entity of a mechanism is stable enough if its properties and boundaries remain stable while the phenomenon for which that mechanism is responsible is taking place. For example, component entities of a circulatory system (heart, lungs, veins…) are stable enough. Their properties and boundaries remain stable while blood circulates and transports blood cells, carbon dioxide, hormones, nutrients, and oxygen. However, the application of this requirement of stability to evolutionary causes' parts would be problematic. Firstly, it would be very difficult to determine which degree of stability must be required to a part of an evolutionary cause. Evolutionary causes are often responsible for several phenomena with different timescales. As it has been argued (see Sect. 4), each evolutionary cause is responsible for several phenomena or outcomes. For instance, genetic drift is responsible for the fixation of certain new mutations, the removal of genetic variation in populations, the increment of differentiation among populations, etc. Likewise, mutation is responsible for the change in gene frequency, the increment of variation within subpopulations, the decrease of variation among subpopulations, etc. Phenomena for which an evolutionary cause is responsible often do not have the same duration. Frequently, one phenomenon for which the cause is responsible has finished while others are still taking place. For example, a new mutation may have already been fixated in a population by drift while the increment of differentiation among populations is still taking place. This plurality of phenomena and timescales means that there is not a unique phenomenon's timescale associated to each particular evolutionary process. Therefore, it would not be clear which timescale should be the reference for the requirement of stability and which degree of stability should be demanded. Secondly, properties of parts of evolutionary causes do not always remain stable while those causes and phenomena for which they are responsible are taking place. Evolutionary causes' parts often undergo changes during the evolutionary processes. For example, consider genetic drift and migration. Individual organisms are component parts of those processes. In genetic drift, individual organisms are subject to environmental influences which do not depend on their physical characteristics. Likewise, migration involves individual organisms that move from one population to another. However, individual organisms' properties do not always remain stable while drift or migration processes are taking place. In this manner, phenotypic plasticity (Pigliucci 2001) may change some individual organisms' properties such as colour skin, height, or even reproduction mode during a process of drift or migration. This is also the case for natural selection. At the present time, there is a debate about which are the parts of natural selection (see Glennan 2009; Millstein 2006; Otsuka 2016). Some authors consider that parts of natural selection are individual organisms while other authors argue that they are populations. Nevertheless, in both cases parts of natural selection would not be stable enough. Individual organisms' properties may change while a process of natural selection is taking place. Those changes may be produced by phenotypic plasticity, but they may also be a consequence of certain circumstances during organisms' lifespan. Imagine an individual male organism that, during a process of sexual selection, loses an eye fighting against a competing male. Although that wound may not affect its reproductive fitness, some of its properties would have significantly changed during the evolutionary process. Likewise, populations' properties and boundaries change while a process of natural selection is taking place. There is always a change in the mean (or higher moments) distribution of certain traits in populations during processes of natural selection. Besides, populations' boundaries change because of births and deaths.

Regarding problems related with productive aspects, Glennan's notion of activity does not account for many productive relationships that occur in evolutionary processes. Glennan characterizes productive relationships within mechanisms as activities. Activities are processes that involve change through time, in which at least one entity (or part) is engaged. One trait of activities is that they "require entities (parts, components) to act and be acted upon" (Glennan 2017, 31). However, this characterization of activities does not fit many productive relationships within evolutionary processes. Productive relationships among parts of evolutionary causes are possible even if none of them has been acted upon. For example, consider a process of frequency-dependent selection. Imagine a population of birds composed by two types: green and blue. Predators see much better green organisms than blue ones, making them decrease their frequency, and increasing blue organisms' frequency. In this example, there is a productive relationship between both bird types. Blue type has increased its frequency because green types are easier to see by predators. Nevertheless, blue types have not been acted upon by green types. This productive relationship within a process of natural selection does not suit Glennan's notion of activity.

In addition to the previously outlined difficulties, Glennan's proposal would also face the functional view's problem regarding the identification and delimitation of evolutionary causes (see Sect. 4). As functional view's advocates, Glennan argues that a mechanism is always a mechanism for a phenomenon and that "[a] phenomenon is what is used to identify and delimit its mechanism" (Glennan 2017, 23). He considers that a mechanism is composed of those entities, activities, and organizational features that contribute to the phenomenon for which it is responsible. It would mean that the mechanism responsible for each phenomenon or outcome is different. However, as it has been noted, this approach does not suit evolutionary biologists' ideas about the identification and delimitation of evolutionary causes. They do not consider that for each outcome of causal evolution there is a different evolutionary cause which is responsible for it. For them, a particular evolutionary cause may be responsible for several outcomes.

6 Conclusion

As we have noted, there is no consensus about how the causes of evolution should be understood (see Sect. 2). Thus, we consider that it is relevant to study whether a mechanistic framework can account for evolutionary causes. If it were successful, it would bring us some benefits. Some of those would be (1) it would make possible to explain without laws (which are not present in some cases of evolution); (2) it would offer helpful possibilities of representation (e.g. spatial representation, colours, etc.) which are not available in other frameworks (e.g. probabilistic, counterfactual, etc.); (3) the appellation to mechanisms may be used to support causal claims; (4) mechanisms would connect different ontological levels; and (5) it would reveal an underlying link between evolutionary biology and other fields of biology where the mechanistic framework is generally accepted (e.g. molecular biology, biochemistry, etc.).

However, as we have showed through the present article, the mechanistic framework is faced with outstanding difficulties. Current mechanistic approaches to causal evolution have problems for accounting for natural selection and the other evolutionary causes as mechanisms. The stochastic view, in addition to unjustifiably assume the stochastic character of natural selection, must admit either that not all evolutionary causes are mechanisms or that evolutionary causes are mechanisms of very different types—which would make difficult to account for their relations and dynamics. Likewise, the functional view erroneously postulates that natural selection's function is to produce adaptation and faces the problem that evolutionary causes produce several outcomes and it is not clear which would be their function. Finally, the minimalist view, which considers mechanisms in general, does not take into account the specific traits of evolutionary causes and cannot account for their parts and productive relationships.

Given the issues above noted, it is possible to raise some requirements that a fruitful and encompassing mechanistic approach for evolutionary theory should meet. Firstly, it should account for all evolutionary causes as similar processes in order to satisfy biologists' considerations, and therefore it should not accept excessive heterogeneity on what is considered an evolutionary mechanism. Secondly, it should find out common characteristics not based in regularity. A particular kind of regularity (to be stochastic, to be deterministic, etc.) cannot be among the requirements for defining evolutionary mechanisms. Thirdly, it should take into account the interactions between different evolutionary causes. This is something that no one has faced, since almost all discussions have been around natural selection. A mechanistic common framework demands specifying how interactions among evolutionary mechanisms are, using a common measure for all mechanisms, etc. Related to this, evolutionary mechanisms should be conceptualized in an operative way, allowing us to build tractable (mathematical) models. Thus, these models would show the dynamics among evolutionary mechanisms, underline relationships, etc., offering the kind of things that a common framework does. Therefore, an excessive heterogeneity would violate that feature. Finally, a mechanistic approach could take into account several hierarchical or ontological levels. This is important because there is no consensus about whether the causes of evolutionary change belong to the level of individuals (Bouchard and Rosenberg 2004), or whether the causes of evolution should be better understood as population-level causes that act on the entire population (Millstein 2006). In contrast, mechanisms are able to deal with different hierarchical levels, showing at the same time individual and population-level interactions. Nevertheless, this is conditional upon the satisfaction of previous points. That is, taking into account different levels could lead to a proliferation of variables –because you are explicitly exposing individual and population interactions of several mechanisms–, potentially producing an inoperative framework (for instance, mathematically intractable, requirements of too much data, etc.). This unpleasant result would reduce its attractiveness as a common framework for biologists.[14]

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[14] There is a related worry. It might also be the case that a mechanistic approach is able to conceptualize evolutionary factors as mechanisms, in an isolated way, but it is not able to express the interactions between different mechanisms.

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Mechanistic explanations and components of social mechanisms

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Abstract: The past two decades have witnessed an increase in interest in social mechanisms and mechanistic explanations of social macro-phenomena. This paper addresses the question of what the components of social mechanisms in mechanistic explanations of social macro-phenomena must be. Analytical sociology's initial position and the main new proposals by analytical sociologists are discussed. It is argued that all of them are faced with outstanding difficulties. Subsequently, a minimal requirement regarding the components of social mechanisms is introduced. It is held that a component of a social mechanism in a mechanistic explanation of a social macro-phenomenon must not have the *explanandum* phenomenon as a part of it.

Keywords: mechanism; scientific explanation; analytical sociology; structural individualism.

1. Introduction

The past two decades have witnessed an increase in interest in social mechanisms (i.e. mechanisms for social macro-phenomena) and mechanistic explanations of social macro-phenomena. This increase has been related with the development of analytical sociology.[1] Analytical sociology is a methodological movement within sociology that underlines the relevance of social mechanisms (Elster 1989, 2007; Hedström 2005; Hedström and Bearman 2009b; Hedström and Ylikoski 2010).[2] Analytical sociologists claim that the main aim of sociology should be to explain social macro-phenomena (e.g. racial segregated neighbourhoods) by means of the mechanisms that are responsible for them (Hedström 2005). They also consider that the notion of mechanism is helpful for addressing other issues such as causation and scientific knowledge growth (Hedström and Ylikoski 2011).

The aim of this paper is to address the question of what the components of social mechanisms in mechanistic explanations of social macro-phenomena must be (henceforth, "the question of components"). Addressing this question is crucial for the development of the mechanistic account of scientific explanation in social science. Mechanistic explanations must specify the mechanisms responsible for the *explanandum* phenomena, which requires identifying their components. In that kind of explanations, it is fundamental to detail how the components of the mechanism together give rise to the phenomenon. Consequently, knowing what the components of social mechanisms in mechanistic explanations of social macro-phenomena must be is essential for building mechanistic explanations. Throughout the paper, in order to address the question of components, legitimate mechanism-based explanations of social macro-phenomena will usually be taken as reference. Those explanations are one of the main guidelines for developing and evaluating potential

[1] In this paper, I will focus on analytical sociology, which is the main approach in the discourse on social mechanisms and mechanistic explanations in social science. Nevertheless, it should be noted that there are several authors who have addressed those issues from alternative perspectives (see Bunge 1997, 2004; Tilly 2000, 2001, 2004; Abbott 2007; Gross 2009).

[2] For an exhaustive exposition of the emergence of analytical sociology and its relationship with previous proposals see (Manzo 2010).

answers to that question (see, for instance, Hedström and Bearman 2009a). The structure of the paper is as follows. Section 2 presents the fundamental principles of analytical sociology, its initial position with respect to the question of components, and the main critique against that position. Sections 3 and 4 analyse the main proposals regarding the question of components that have been raised by analytical sociologists after the critiques against their initial position. It is argued that they are faced with outstanding difficulties. Section 5 introduces a minimal requirement that must be fulfilled by components of social mechanisms in mechanistic explanations of social macro-phenomena. It is held that a component of a social mechanism in a mechanistic explanation of a social macro-phenomenon must not have the *explanandum* phenomenon as a part of it. Finally, section 6 concludes.

2. The fundamental principles of analytical sociology

A core idea of analytical sociology is the principle of mechanism-based explanations. Although analytical sociology is not a completely homogenous movement, all analytical sociologists support the mechanistic account of scientific explanation. Mechanistic explanations in sociology are proposed as an alternative to covering-law explanations and statistical explanations (Hedström 2005). Both covering-law and statistical explanations are black-box explanations.[3] This kind of explanations is characterized by considering that either the link between *explanans* and *explanandum* is devoid of structure or its structure has no explanatory interest (Hedström and Swedberg 1998). They do not address the processes that would allow us to understand how *explanans* and *explanandum* are actually linked.

Analytical sociologists consider that a social macro-phenomenon is explained by specifying the mechanism by which that phenomenon is brought about (Hedström 2005; Hedström and Bearman 2009b; Hedström and Ylikoski 2011). Mechanism-based explanations open up the black box that connects *explanans* and *explanandum* and detail the social cogs and wheels of the causal process through which the *explanandum* is produced. They oppose black-box explanations, "the mechanism should not include any glaring black boxes which simply give raise to additional why-questions" (Hedström 2005, p. 26). Unfortunately, there is no consensus on the notion of mechanism. Within the framework of analytical sociology, several notions of mechanism have been adopted (see Mahoney 2001; Hedström 2005). Nevertheless, all notions share some basic aspects (Hedström and Ylikoski 2010). First, a mechanism is always a mechanism for a phenomenon. It is identified and delimited by reference to the phenomenon for which it is responsible. Second, a mechanism involves causal aspects. It refers to causal processes in which its component entities are engaged. Third, a mechanism has a structure. A mechanism consists of a structured constellation of entities and activities. Fourth, mechanisms are nested and form a hierarchy. A mechanism at one level presupposes or takes for granted certain entities and activities, but there are often lower-level mechanisms that account for them.

An example of a mechanistic explanation of a social macro-phenomenon is Matthew J. Salganik, Peter Sheridan Dodds, and Duncan J. Watts' explanation of why successful cultural products (e.g. best-

[3] For other critiques against covering-law explanations and statistical explanations in social science see (Hedström 2005).

selling books, hit songs…) are orders of magnitude more successful than average (Salganik et al. 2006; Salganik and Watts 2009). The authors explain this social macro-phenomenon by specifying how the behaviour of individuals produces it. Social influence is present in cultural markets, where information about the success of offered products is often available (e.g. best sellers lists). Due to the huge amount of offered cultural products, individuals are likely to follow others' choices and buy those products that are already successful. This tendency is also reinforced by structural features of many cultural markets, such as giving best-selling books more prominent in-store placement. Therefore, cumulative advantage operates. Cultural products that are successful tend to become still more successful. Initially small differences become large differences and, consequently, inequality increases. In cultural markets, social influence at the level of individuals leads to inequality of success at the macro level. In Salganik, Dodds, and Watts' work, the presence of social influence in cultural markets and its contribution to inequality of success are supported by an experimental study in an artificial cultural market (Salganik et al. 2006). They created a website in which participants listened and downloaded previously unknown songs with or without knowledge of previous participants' downloads. That experiment strongly suggested that individuals' behaviour was influenced by others' choices and that social influence contributed to inequality of success. When knowledge of previous participants' choices (and songs' popularity) was available, individuals were more likely to download popular songs (i.e. the most previously downloaded songs) than when that information was not available. Moreover, inequality of success was greater in the social-influence condition (i.e. when knowledge of previous participants' choices was available) than in the independent condition.

The other fundamental principle of analytical sociology is structural individualism (Hedström 2005; Hedström and Ylikoski 2010, 2011). It is "a doctrine according to which all social facts, their structure and change, are in principle explicable in terms of individuals, their properties, actions, and relations to one another." (Hedström and Ylikoski 2010, p. 60). Structural individualism is a weak version of methodological individualism (Udehn 2001). It considers that social macro-phenomena must be explained in terms of interactions of individual agents. Individuals are the main entities and their actions are the main activities that give rise to social macro-phenomena. However, structural individualism admits that not all explanatory facts are about individuals in the strict sense. Relations and relational structures (e.g. topologies of social networks) may be explanatorily relevant. They influence in individuals' behaviour and in social outcomes brought about. Salganik, Dodds, and Watts' (2006) explanation of inequality of success in cultural markets meets the requirements of structural individualism. The *explanandum* social macro-phenomenon is explained in terms of individuals, their properties, actions, and relations. The authors refer to a social mechanism whose components are individual consumers, their properties (e.g. having certain taste, being influenced by others' choices…), activities (e.g. listening, buying, downloading…), and relations. It should be particularly noted that their explanation includes references to relations among individuals and relational structures, which is the main aspect that distinguishes structural individualism from other versions of methodological individualism. For instance, it is specified how individuals' choices are influenced by the way in which other individuals' behaviour is showed. It is claimed that the more highlighted is the previous behaviour of individuals, the stronger is the effect of social influence.

The principles of mechanism-based explanations and structural individualism are not considered independent. Analytical sociologists hold that the principle of mechanism-based explanations implies structural individualism.[4] In this sense, Hedström and Ylikoski say: "The methodological individualism of analytical sociology [i.e. structural individualism] is a consequence of its account of scientific explanation, not an independent metaphysical doctrine" (2011, p. 393). Their main argument in support of that idea is that there are social mechanisms only at the individual level (Hedström and Swedberg 1998; Hedström 2005). Due to the discipline-specific relevance criteria, social mechanisms are always at the individual level. All social mechanisms are composed of individuals, their properties, actions, and relations. Higher level mechanisms, which would include glaring black-boxes, and lower level mechanisms, which would entail an excessive decomposition of their parts, would hardly be considered relevant by social scientists. Consequently, demanding mechanistic explanations would mean demanding explanations in terms of individuals, their properties, actions, and relations. Structural individualism would be an unavoidable consequence of the principle of mechanism-based explanations. According to analytical sociologists, one could not adopt the principle of mechanism-based explanations in sociology without accepting structural individualism. Supporting a mechanistic account of scientific explanation in sociology would require a commitment to the idea that a social macro-phenomenon must be explained in terms of interactions of individual agents. The commitment to structural individualism leads to an answer to the question of components: a social mechanism in an explanation of a social macro-phenomenon must be composed of individuals, their properties, actions, and relations to one another. This is the analytical sociology's initial position regarding the question of components.

In response to the analytical sociology's initial answer to the question of components, several authors have disputed the idea that the principle of mechanism-based explanations implies structural individualism (Kincaid 2004; Mayntz 2004; Vromen 2010; Wan 2012; Kaidesoja 2013). They have argued that it is unlikely to be the case that all social mechanisms are at the individual level.[5] Therefore, analytical sociologists' main argument in support of the implication between both principles would not hold and, consequently, their initial position regarding the question of components would not be justified. Those authors claim that a mechanism for a social macro-phenomenon does not have to be exclusively composed of individuals, their properties, actions, and relations. It must be composed of organized entities and activities, but those need not be only individuals, their properties, actions, and relations. Macro social mechanisms (i.e. social mechanisms that have components of a level higher than the individual level) are possible. Their component entities are either collective agents (e.g. firms, political parties, universities…) and individuals or just collective agents. A paradigmatic example of macro social mechanism is firms competing for market shares in a competitive market. It is composed of firms, their properties (e.g. reputation), activities (e.g. launching an advertising campaign), and relations (e.g. trade partnership). Other illustrative examples of macro social mechanisms would be a coalition of political parties, a conflict between trade unions, or states allied against an environmental problem.

[4] It is generally accepted that structural individualism does not imply the principle of mechanism-based explanations (Ylikoski 2011). Explanations of social macro-phenomena in terms of individuals' interactions are possible even if the mechanisms responsible for them are not specified.

[5] This idea was originally introduced by Stinchcombe (1991) (although he understood mechanisms as abstract entities). Stinchcombe held that, in social mechanisms, units of analysis can be individuals, social actors, situations, or patterns of information. He argued that, while units of analysis are generally at a lower level than the *explanandum*, they do not need to be individuals.

The previously analysed discussion could be briefly summarized as follows. The two fundamental principles of analytical sociology are the principle of mechanism-based explanations and the structural individualism. Analytical sociologists consider that the principle of mechanistic explanations implies structural individualism because there are social mechanisms only at the individual level. The commitment to structural individualism leads to their initial position regarding the question of components: a social mechanism in an explanation of a social macro-phenomenon must be composed of individuals, their properties, actions, and relations to one another. However, as it has been argued, not all social mechanisms are at the level of individuals and, consequently, the principle of mechanistic explanations hardly implies by itself structural individualism. Therefore, the analytical sociology's initial position would not be properly supported.

Given the critiques against the analytical sociology's initial position regarding the question of components, different answers have been raised by analytical sociologists. In the next two sections, I will analyse the main responses: the proposal of Michael Schmid (2011), who supports the analytical sociology's initial position by means of a new argument, and the proposal of Petri Ylikoski (2012), who defends a perspectival version of that position. It will be argued that both of them are unable to offer a proper answer to the question of components.

3. The new argument by Schmid

Schmid (2011) maintains the analytical sociology's initial position regarding the question of components. He claims that a social mechanism in an explanation of a social macro-phenomenon must be composed of individuals, their properties, actions, and relations to one another. He also adopts the principle of structural individualism regarding mechanism-based explanations, which leads to that position in relation to the question of components. However, his argument in support of that principle is not based on the idea that there are social mechanisms only at the individual level. He considers that mechanistic explanations of social macro-phenomena require mechanisms at the individual level, but he does not explicitly deny the existence of social mechanisms at other levels.

Firstly, Schmid claims that one aspect of mechanism-based explanations in social science is that they require "*laws* indicating which factors ultimately 'produce' or 'generate' a relevant event" (2011, p. 137). Specifying nomological connections is necessary in mechanistic explanations. Following the covering-law theory of explanation (Hempel 1965), he argues that the *explanandum* social macro-phenomenon must be deduced from the *explanans* by means of laws. Although Schmid does not make it explicit, the acknowledged influence of the Hempelian approach suggests that he is understanding laws in a similar way as Hempel does, i.e., as true lawlike statements. And secondly, Schmid argues that we do not know any social law, i.e., a law governing the course of social macro-processes (e.g. a developmental law of society). All candidates to social laws have been proved to be false. In social sciences, only laws of individual action are available. Those laws address how individuals determine their actions in view of their established goals and subjective information. From those ideas, Schmid concludes the principle of structural individualism regarding mechanism-based explanations. He claims that "social phenomena may be regarded as having been explained *only* when their genesis, operation and reorganization (in the last instance) is accounted for on the basis of the individual adaptive actions of individual actors" (Schmid 2011, p. 144). Structural individualism, as it has been noted, leads to the analytical sociology's initial position regarding the question of components.

Schmid's argument in support of the principle of structural individualism in relation to mechanism-based explanations may be reconstructed as follows:

(1) Mechanism-based explanations of social macro-phenomena must include laws.

(2) In social science, the only laws available range over individuals, their properties, actions, and relations.

Mechanistic explanations of social macro-phenomena must refer to individuals, their properties, actions, and relations.

It is a valid argument. The truth of the premises supports the truth of the conclusion. If its premises were true, it would follow the principle of structural individualism regarding mechanism-based explanations. However, I think that one of the premises of the argument is probably not true. The first premise, which is supposed to present a trait of mechanism-based explanations, is likely to be inaccurate. Although subsumption under laws is a requirement in the traditional covering-law model of scientific explanation, mechanistic explanations are not required to include laws (Halina 2018).[6] In fact, the mechanistic account of scientific explanation has been developed as an alternative to those accounts that require to specify laws (Betchel and Abrahamsen 2005; Hedström 2005). One of the main critiques against the covering-law model was that few or no laws are known in several fields of science (Scriven 1959). That model focuses on certain domains of physics, where many laws are known, and ignores the absence of laws in fields such as biology, sociology, economics, psychology, neuroscience, etc. The mechanistic account of scientific explanation aims to account for explanations in those fields where laws are not available. Therefore, not requiring to indicate laws is a characteristic trait of mechanism-based explanations. In a mechanistic explanation, the *explanandum* is explained by uncovering the mechanism that is responsible for it, and specifying laws is not required for that. It is not necessary to demonstrate that activities in which mechanisms' component entities engage are according to laws.[7] Those activities are often characterized just as processes that involve change through time (Glennan 2017) or happenings that produce changes (Machamer 2004). In fact, most mechanism-based explanations do not include laws. For instance, consider Michael Mann's (2004) analysis of the success of European fascism in the interwar period. In his analysis, Mann addresses the property of certain countries (e.g. Britain, France, Sweden…) of not being susceptible to fascist movements seizing power. He offers a mechanism-based explanation of this social macro-property. That explanation refers to a mechanism whose main components are the political parties of those countries and some of their properties, such as subscribing "an instrumental rationality of means not ends" (Mann 2004, p. 90) and

[6] Karl-Dieter Opp (2005) has argued that mechanistic explanations must include laws because "[o]nly a law provides a *selection criterion* for the factors that have caused a phenomenon" (2005, p. 174) and without them the election of explanatorily relevant factors is arbitrary. Nevertheless, new mechanists have raised several alternative criteria of explanatory relevance in mechanistic explanations. For instance, Carl Craver (2007, p. 153) has introduced the requirement of mutual manipulability and Stuart Glennan (2017, p. 43) has proposed the requirement of contributing to the activity of the mechanism as a whole.

[7] In the first version of his notion of mechanism, Glennan (1996) considered that interactions among parts of mechanisms must be according to direct causal laws. Nevertheless, Glennan (2002, 2017) has later modified his characterization of interactions among mechanisms' parts and removed that requirement.

being accustomed to "[c]eding sovereign powers to the opponent if electorally defeated" (Mann 2004, p. 90). Mann shows that those properties were relevant with respect to the countries' property of not being susceptible to fascist movements seizing power. Nonetheless, Mann's explanation does not include any law. He does not specify a nomological connection between political parties' properties and countries' susceptibility to fascist movements seizing power. The absence of laws in mechanistic explanations is common to most fields of science. Paradigmatic examples of neuroscientific mechanistic explanations (e.g. explanation of neurotransmitter release), for example, do not include laws either (Craver 2007).

As a matter of fact, the idea that mechanism-based explanations must include laws would not even be accepted by most analytical sociologists. They consider that mechanistic explanations are an alternative to covering-law explanations (see section 2) and do not require specifying laws. In this sense, Hedström and Ylikoski say: "Of course, mechanism-based explanations still rely on causal generalizations about the properties, activities, and relations of underlying entities, but they do not have to satisfy the traditional criteria for laws" (2010, p. 55).

Summing up, Schmid adopts a conservative strategy in response to the critiques against the analytical sociology's initial position regarding the question of components. He presents a new reasoning in support of that position, which is also based on the adoption of the principle of structural individualism. His proposal avoids the previously criticized idea that there are social mechanisms only at the individual level. However, his new argument in support of structural individualism is built on a very problematic premise: mechanistic explanations must include laws. As it has been noted, it is unlikely to be the case that mechanism-based explanations are required to specify laws. Schmid fails to justify the principle of structural individualism regarding mechanism-based explanations. Therefore, his proposal does not properly support the analytical sociology's initial position regarding the question of components. Schmid does not offer a justified answer to the question of components.

4. The perspectival version by Ylikoski

Unlike Schmid, Ylikoski (2012) advocates a modified version of the analytical sociology's initial position regarding the question of components. In his proposal, the initial demand of individual-level components is replaced by a demand of micro-level components. Micro-level components can but not need to be at the level of individuals. The micro level is perspectival in the sense that it is dependent on the explanatory target.

Analytical sociologists usually consider that all mechanistic explanations of social macro-phenomena are causal explanations (Hedström 2005; Hedström and Ylikoski 2010; Demeulenaere 2011). In this sense, Hedström claims that "[t]he core idea behind the mechanism approach is that we explain […] by specifying mechanisms that show how phenomena are brought about" (2005, p. 24). However, Ylikoski (2012, 2013) has recently argued that mechanistic explanations of social macro-phenomena may be constitutive explanations too. Ylikoski considers that both causal and constitutive explanations "track networks of counterfactual dependence" (Ylikoski 2012, p. 34). The *explanans* must be a difference-maker with respect to the *explanandum*. X explains Y if Y depends on X in the sense that if X had not happened, Y would have not happened either (Woodward 2003; Ylikoski 2013). Nevertheless, causal and constitutive explanations track different sort of counterfactual dependencies: "[c]ausal explanations appeal to etiological counterfactuals, while constitutive counterfactuals are the material for constitutive explanations" (Ylikoski 2013, p. 290). Although both causation and constitution are relations of dependence, there are relevant metaphysical differences between them. Causation is often a relation between events (i.e. changes in the properties of entities), takes time, and is asymmetric regarding manipulation (i.e. a change in the effect can be produced by manipulating the cause, but not the other way around). Constitution is often a relation between causal capacities (i.e. properties of entities), is synchronic, and is symmetric regarding manipulation (i.e. a change in the whole can be produced by manipulating a part of it, and vice versa). Causal explanations include parts of the causal history of the *explanandum* event that are causally relevant for it (i.e. there are causal counterfactuals that relate them), while constitutive explanations include parts of the system whose property is the *explanandum* that are constitutively relevant for it (i.e. there are constitutive counterfactuals that relate them). Ylikoski (2013, p. 291) considers that both causal and constitutive explanations can be mechanistic if they tell why and how the counterfactual dependencies hold. Causal mechanism-based explanations must specify the mechanism that brings about the *explanandum* event, whose components are causally relevant for it, and constitutive mechanism-based explanations must specify the mechanism that gives rise to the *explanandum* property, whose components are constitutively relevant for it.[8]

Taking the distinction between constitutive and causal mechanism-based explanations as reference, Ylikoski addresses the question of components. Firstly, he focuses on constitutive mechanistic explanations of social macro-phenomena. Ylikoski considers that "[t]he *explanantia* in constitutive explanations are always at the micro level" (Ylikoski 2012, p. 35). Constitutive explanations aim to show how *explanandum* macro-phenomena "are constituted by micro-level entities, activities and relations" (Ylikoski 2012, p. 35). Consequently, he claims that the components of social mechanisms in constitutive mechanism-based explanations of social macro-phenomena must be located at the micro level. Secondly, Ylikoski addresses causal mechanistic explanations of social macro-phenomena. He acknowledges that the *explanantia* in causal explanations are not always at the micro level. Unlike the notion of composition, "nothing in the notion of causation implies that the real causal work is always to be found at the micro level" (Ylikoski 2012, p. 36). Causally relevant entities, properties, activities, and relations do not need to be at the micro level. For example, the marketing strategy of a courier firm is causally relevant (i.e. there are causal counterfactuals that relate them) for the market shares of other firms that provide courier services in the same area. Nevertheless, Ylikoski considers that causal mechanistic explanations of social macro-phenomena require microfoundations. Appealing to micro-level entities, properties, activities, and relations is essential for understanding how the explanatory counterfactual dependencies hold. Consequently, he argues that the components of social mechanisms in causal mechanism-based explanations of social macro-phenomena must be located at the micro level. Ylikoski concludes that, despite their relevant differences,

[8] Several new mechanists (e.g. Craver 2007) consider that the *explanandum* of a constitutive mechanistic explanation is a behaviour of a system. However, Ylikoski (2013) argues that the notion of behaviour can refer to both properties and events, and is potentially confusing. He claims that *explananda* of constitutive mechanism-based explanations must be characterized as properties of entities.

in both constitutive and causal mechanistic explanations of social macro-phenomena, social mechanisms must be composed of micro-level entities, properties, activities, and relations.

Ylikoski's proposal is less rigid than the analytical sociology's initial position regarding the question of components. He holds that components of social mechanisms in mechanism-based explanations of social macro-phenomena must be micro-level entities, properties, activities, and relations. Nonetheless, he considers that there is not a unique and predetermined micro level (e.g. the individual level) to which components of social mechanisms must always belong. The distinction between micro and macro is understood as a question of scale: "the difference between small- and large-scale social phenomena" (Ylikoski 2012, p. 27). What is considered as micro-level entities, properties, activities, and relations depends on the *explanandum* phenomenon (and the explanatory interests). A component could be considered micro regarding certain social phenomenon but not regarding another one. As an example, take into account regional governments. A regional government would be considered a micro entity regarding the gross domestic product of a country but not regarding the performance of town councils. Although micro-macro relations involve differences in scale, all differences in scale do not constitute legitimate micro-macro relations. For instance, between people's literary preferences and countries' migration policies there is a difference of scale, but it hardly constitutes a micro-macro relation. Nonetheless, Ylikoski acknowledges that it is difficult to identify the additional traits that characterise legitimate social micro-macro relations and differentiate them from other differences in scale. He considers that it is only possible to underline some traits that are often present in social micro-macro relations. For example, many social micro-macro relations are part-whole relationships and macro social facts are usually supra-individual.

Ylikoski's perspectival version avoids the main difficulty of the analytical sociology's initial approach to the question of components. It is compatible with the fact that not all social mechanisms are at the individual level. In that proposal, it is considered that micro components of social mechanisms may be at different levels. Ylikoski's approach also avoids the problem of Schmid's argument. In it, it is not required that mechanism-based explanations of social macro-phenomena include laws. Nevertheless, the perspectival proposal developed by Ylikoski faces some relevant difficulties.

The main problem of Ylikoski's proposal is that it is too vague and, consequently, does not constitute a proper answer to the question of components. In order to avoid the problem of the analytical sociology's initial position, the requirement of individual-level components is substituted by the requirement of micro-level components. Nevertheless, the notion of micro level is not accurately characterised. The micro-macro relation is defined as a particular kind of difference in scale. But the traits that characterise it and distinguish it from other differences in scale are not identified. It is always ambiguous whether the components of a social mechanism are at the micro level and meet the requirement.

Another problematic aspect of Ylikoski's proposal is that it does not provide a guide for building mechanism-based explanations of social macro-phenomena. Firstly, as it has been noted, it is not concrete enough. It is never certain if a particular entity, property, activity or relation is at the micro level. And secondly, the identification of the micro level would require the previous specification of the *explanans* and the *explanandum*. In order to belong to the micro level, a component must be explanatorily relevant for the *explanandum* macro-phenomenon. In this sense, Ylikoski says: "Macro-level facts are explained by appealing to micro-level processes, entities, and relations, but these items belong to the micro level just because they are required for the full explanation of the macro fact" (2012, p. 25). Consequently, it would not be possible to identify which entities, properties, activities, and relations are at the micro level before the development of the explanation.

Finally, despite being less rigid than analytical sociology' initial approach, Ylikoski's proposal does not suit many mechanism-based explanations of social macro-phenomena. In social science, causal mechanistic explanations of social macro-events often include causal relevant entities, properties, activities, or relations that are unlikely to be at the micro level. An example can be found in Aaron M. McCright and Riley E. Dunlap's (2003) analysis of the conservative movement's impact on the United States climate change policy. They provide a causal mechanism-based explanation of the no ratification of the Kyoto Protocol by the United States senate. Conservative movement saw the concern over global warming as threatening American industry, prosperity, and lifestyle. It considered that changes resulting from efforts to ameliorate the global warming would harm American economy. Because of those worries, conservative think tanks (e.g. Cato Institute, Heritage Foundation, Marshall Institute…) challenged the legitimacy of global warming as a problem by means of diverse strategic activities, such as publishing documents (e.g. policy studies), producing advertisements, presenting their global warming counter-claims to policy makers in Congressional hearings, and appearing on television programs. Their activities and their collaboration with American climate change sceptics eventually produced a redefinition of global warming as non-problematic. That redefinition influenced in the policy arena and brought about the no ratification of the Kyoto Protocol by the United States senate. In McCright and Dunlap's causal mechanism-based explanation, most components of the social mechanism are hardly at the micro level. Firstly, there is not a clear difference in scale between them and the *explanandum* macro-phenomenon. For instance, consider think thanks' challenge of the legitimacy of global warming as a problem. It does not seem reasonable to consider it a small-scale activity and the no ratification by the senate a large-scale phenomenon. Both are supra-individual events, and there is no relevant difference between them that supports that differentiation. And secondly, even if there was a difference in scale between them, the relation between the components of the mechanism and the *explanandum* would hardly constitute a meaningful micro-macro relation. The traits that usually characterise micro-macro relations are not present there. For example, there is not a part-whole relationship between them. United States conservative movement, American network of climate change sceptics, and think thanks are not part of the United States senate.

In summary, Ylikoski defends a modified version of the analytical sociology's initial position regarding the question of components. The requirement of individual-level components is substituted by the requirement of micro-level components. He claims that components of social mechanisms in mechanism-based explanations of social macro-phenomena must be micro-level entities, properties, activities, and relations. That proposal avoids the problems of the analytical sociology's initial position and of the Schmid's argument. Nevertheless, it faces relevant difficulties. As it has been argued, it is too vague, it does not provide a guide for building mechanism-based explanations, and it does not suit many causal mechanistic explanations of social macro-phenomena. Ylikoski does not offer a satisfactory answer to the question of components either.

5. A minimal requirement

Analytical sociologists' proposals regarding components of social mechanisms in explanations of social macro-phenomena face outstanding difficulties. Nevertheless, I consider that it is possible to offer a proper response to the question of components. The aim of this section is to present a minimal requirement regarding the components of social mechanisms, which applies to both causal and constitutive mechanistic explanations of social macro-phenomena.

Mechanism-based explanations of social macro-phenomena can be causal or constitutive explanations (Ylikoski 2012, 2013). In a mechanistic explanation, the *explanandum* phenomenon is explained by specifying the mechanism that is responsible for it. But the relation between the *explanandum* social macro-phenomenon and the social mechanism responsible for it may be causal or constitutive. Causal mechanistic explanations of social macro-phenomena include parts of the causal history of the *explanandum* that are causally relevant for it, while constitutive mechanistic explanations include parts of the system whose property or behaviour is the *explanandum* that are constitutively relevant for it. An example of a causal mechanistic explanation of a social macro-phenomenon is Salganik, Dodds, and Watts' (2006) explanation of inequality of success in cultural markets (see section 2). They specify how the behaviour of individual consumers, which is socially influenced, brings about that inequality. Other examples of causal mechanistic explanations are McCright and Dunlap's (2003) explanation of the failure of the United States to ratify the Kyoto Protocol, and Katherine Stovel and Christine Fountain's (2009) explanation of the persistence of segregation in the labour market. An example of a constitutive mechanistic explanation of a social macro-phenomenon is Mann's (2004) explanation of the property of certain European countries of not being susceptible to fascist movements seizing power (see section 3). He specifies how certain properties of the components of those countries (e.g. political parties) constituted the property of interest. Other examples of constitutive mechanistic explanations could be a mechanistic explanation of a property of a parliament (e.g. liberals having an absolute majority), and a mechanistic explanation of the differences in the problem-solving capacities of two groups (Ylikoski 2012).

There is no privileged level to which components of social mechanisms in mechanistic explanations of social macro-phenomena must always belong. Neither in causal mechanism-based explanations nor in constitutive mechanism-based explanations of social macro-phenomena, must components of social mechanisms always be at certain fixed level. Both causally relevant components and constitutively relevant components may be at diverse levels. As a matter of fact, components of social mechanisms included in mechanistic explanations of social macro-phenomena are not always at the same level. Consider Salganik, Dodds, and Watts' (2006) and McCright and Dunlap's (2003) causal mechanism-based explanations. Salganik, Dodds, and Watts refer to a mechanism whose components are at the individual level (e.g. individual consumers), while McCright and Dunlap refer to a mechanism whose main components are collective agents (e.g. think tanks). The same diversity can be found in constitutive mechanism-based explanations. Constitutive mechanistic explanations of the problem-solving capacity of a group refer to mechanisms whose components are at the individual level (e.g. social skills of individual members of the group), while constitutive mechanistic explanations of a property of a parliament often refer to mechanisms whose main components are collective agents (e.g. parliamentary groups) and their properties.

Given this scenario, it could be considered that a proper answer to questions of components is hardly achievable. It seems that proposals that account for the diversity of mechanistic explanations of social macro-phenomena (as Ylikoski's proposal) are too vague and unable to provide a guide for building mechanism-based explanations, while concrete and operational proposals (as analytical sociology's initial position) do not suit the diversity of mechanistic explanations of social macro-phenomena. Nonetheless, I think that a minimal requirement, which is concrete and operational without neglecting the diversity of mechanism-based explanations, can be raised regarding the components of social mechanisms. Particularly, a component of a social mechanism in a mechanistic explanation of a social macro-phenomenon must not have the *explanandum* phenomenon as a part of it. This minimal requirement is concrete enough and provides a guide for building mechanism-based explanations of social macro-phenomena. The identification of parts does not require the previous specification of the *explanans* and the *explanandum*. Moreover, the minimal requirement applies to both causal and constitutive mechanism-based explanations of social macro-phenomena.

In a causal mechanism-based explanation of a social macro-phenomenon, components of the mechanism must not have the *explanandum* phenomenon as a part of them. In order to be a component of the mechanism, an entity or an activity (or another kind of component) must be causally relevant for the *explanandum* phenomenon. An entity or an activity is causally relevant for a phenomenon if there is a relation of causal dependence between them (i.e. there are causal counterfactuals that relate them) (Woodward 2003; Ylikoski 2012). However, there cannot be a relation of causal dependence between an entity or an activity and the *explanandum* phenomenon if the former has the phenomenon as a part of it. A relation of causal dependence is not possible between a whole and one of its parts.[9] It is generally agreed that, in a relation of causal dependence, the relata must be wholly distinct (Hitchcock 2003; Craver and Bechtel 2007; Ehring 2009). Causes and effects must be able to be conceived as independent existences. In this sense, Lewis claims: "C and E must be distinct events – and distinct not only in the sense of non-identity but also in the sense of nonoverlap and nonimplication" (2000, p. 78). Furthermore, causal dependence demands certain requirements that are not satisfied in whole-part relations. For instance, the relation of causal dependence must be asymmetric regarding manipulation and take time (i.e. the relation must not be synchronic) (Craver 2007; Ylikoski 2013). Consequently, in a causal mechanism-based explanation of a social macro-phenomenon, an entity or an activity (or another kind of component) that has the *explanandum* phenomenon as a part of it cannot be a component of the mechanism.

[9] Apparent cases of whole-part (or part-whole) causal relation can be finer understood as causal interactions among parts associated with one or more constitutive relations (Craver and Bechtel 2007). For instance, many putative whole-part causal relations can be analysed as a particular constellation of states of parts, which constitutes certain state of the whole, that causes changes in some parts. Consider, for example, the apparent causal relation between societies' political polarisation and individuals' discrimination against opposing partisans (Iyengar and Westwood 2015). A society's political polarisation is constituted by the divergence of individuals' political attitudes to ideological extremes. Divergence of political attitudes causes affection toward copartisans and animosity toward opposing partisans, and this affective separation results in discriminatory behaviour (in both political and non-political domains) toward opposing partisans.

Likewise, in a constitutive mechanism-based explanation of a social macro-phenomenon, components of the mechanism must not have the *explanandum* phenomenon as a part of them either. In that kind of explanations, components of the mechanism must be proper parts (i.e. parts that are non-identical to the whole) of the system whose property or behaviour is the *explanandum* phenomenon (Craver 2007). Constitutive mechanistic explanations explain the *explananda* by appealing to how the diverse relevant parts together give rise to them. Nevertheless, a component cannot be a proper part of the system whose property or behaviour is the *explanandum* phenomenon if that phenomenon is part of it. If the phenomenon of interest is part of a component, the system whose property or behaviour is that phenomenon is also part of it. For example, if the problem-solving capacity of a team is part of a certain firm, the team is also part of that firm. And if the system is part of the component, the component cannot be a proper part of the system. Something cannot be a proper part of one of its parts (e.g. a society cannot be a proper part of one of its members). Therefore, in a constitutive mechanism-based explanation of a social macro-phenomenon, an entity or an activity (or another kind of component) that has the *explanandum* phenomenon as a part of it cannot be a component of the mechanism.

The proposed minimal requirement constitutes a proper answer to the question of components. Certainly, it does not identify a privileged level (e.g. the level of individuals) to which components of social mechanisms in mechanistic explanations of social macro-phenomena must always belong. As it has been argued, there is no such level. Proposals that seek to identify a privileged level to which components of social mechanisms must always belong are doomed to failure. Nevertheless, the minimal requirement introduces a restriction regarding the relationship between the *explanandum* social macro-phenomena and components of social mechanisms. A component of a social mechanism in a mechanistic explanation of a social macro-phenomenon must not have the *explanandum* phenomenon as a part of it. It should be noted that the proposed requirement does not demand that components of social mechanisms in mechanism-based explanations of a social macro-phenomena must be proper parts of the *explananda*. Certainly, being a proper part of the *explanandum* social macro-phenomenon is a *sufficient condition* to satisfy the minimal requirement. A component that is a proper part of the *explanandum* phenomenon does not have that phenomenon as a part. For example, consider Mann's (2004) mechanistic explanation of the property of certain European countries of not being susceptible to fascist movements seizing power. The components of the social mechanism indicated in the explanation (e.g. political parties' properties), which are proper parts of the *explanandum* (i.e. countries' properties), meet the minimal requirement. However, being a proper part of the *explanandum* social macro-phenomenon is not a *necessary condition* to satisfy the minimal requirement. A component of a social mechanism in a mechanism-based explanation may satisfy the minimal requirement even if it is not a proper part of the *explanandum* phenomenon. A component of a social mechanism would also meet the minimal requirement if it is not constitutively related with the *explanandum* phenomenon. A component is not constitutively related with a phenomenon if and only if there is no part-whole relationship between them; neither is the component part of the phenomenon nor is the phenomenon part of the component. For example, consider the components of a social mechanism in a mechanism-based explanation of a change in certain neighbourhood (e.g. a change in its racial composition). Components such as households that do not belong to that neighbourhood (e.g. households of other neighbourhoods of the same city), which are not constitutively related with the *explanandum* phenomenon, would meet the minimal requirement.

The proposed requirement is less restrictive than the analytical sociology's initial position regarding the question of components and the Ylikoski's perspectival version. The minimal requirement allows those mechanistic explanations of social macro-phenomena that suit the analytical sociology's initial proposal or its perspectival version, but also other legitimate mechanistic explanations that do not suit any of them. A mechanistic explanation of a social macro-phenomenon that suits the analytical sociology's initial proposal would surely satisfy the minimal requirement. If components of a social mechanism in an explanation of a social macro-phenomenon are individuals, their properties, actions, and relations, they do not have the *explanandum* macro-phenomenon as a part of them. Likewise, a mechanistic explanation of a social macro-phenomenon that suits the Ylikoski's proposal would satisfy the minimal requirement. If components of a social mechanism in an explanation of a social macro-phenomenon are at the micro level regarding it, they do not have the *explanandum* macro-phenomenon as a part of them.[10] Nevertheless, the minimal requirement is also satisfied by other legitimate mechanism-based explanations of social macro-phenomena that do not suit those proposals. For example, consider McCright and Dunlap's (2003) explanation of the failure of the United States to ratify the Kyoto Protocol. This mechanistic explanation of a social macro-phenomenon does not suit the analytical sociology's initial proposal. It refers to a mechanism whose components are not just individuals, their properties, actions, and relations to one another. Conservative think tanks are the main component entities of the mechanism. Moreover, as it has been showed (see section 4), that mechanism-based explanation does not suit Ylikoki's perspectival proposal either. It refers to a mechanism whose components are hardly at the micro level. However, McCright and Dunlap's explanation does meet the proposed minimal requirement. The components of the social mechanism referred by McCright and Dunlap (e.g. Cato Institute) do not have the *explanandum* phenomenon (i.e. the failure of the United States to ratify the Kyoto Protocol) as a part of them.

Advocates of more restrictive answers to the question of components could argue that the proposed minimal requirement is too broad and, consequently, ineffective. However, it is unlikely to be the case. Although the minimal requirement is broader than some alternative proposals (e.g. analytical sociology's initial position), it is not so broad that it is ineffective. The minimal requirement introduces an effective restriction regarding the components of social mechanisms in mechanism-based explanations of social macro-phenomena. It excludes those components that have the *explanandum* phenomenon as part of them. This restriction is helpful in order to determine if an explanation of a social macro-phenomenon is a legitimate mechanistic explanation.[11] For example, consider a mechanism-based explanation of a property of the city of London (e.g. a certain degree of economic inequality). If the explanation appealed to a social

[10] As it has been argued (see section 4), in Ylikoski's perspectival proposal, micro-macro relations are not accurately characterised. Consequently, it is difficult to precisely compare that proposal with the minimal requirement. Nevertheless, any sensible characterisation of micro-macro relations would exclude the possibility that a macro-phenomenon is part of a micro component. So, it is reasonable to compare both proposals in those general terms.

[11] It should be noted that failing to satisfy the minimal requirement does not necessarily mean that an explanation is illegitimate or lacks explanatory power. The minimal requirement aims to distinguish legitimate from non-legitimate mechanistic explanations. If a mechanism-based explanation does not meet the minimal requirement, it cannot be considered a legitimate mechanistic explanation. Nonetheless, an explanation that does not meet the minimal requirement could be a legitimate non-mechanistic explanation. For example, an explanation that accounts for people's attitude in terms of the properties of a group to which they belong could be a legitimate non-mechanistic explanation.

mechanism whose components are neighbourhoods (e.g. Chelsea), their properties, actions, and relations, the explanation would satisfy the minimal requirement and it could be a legitimate mechanistic explanation. However, if England or the United Kingdom, which have London and its properties as parts of them, were among the components of the appealed social mechanism, the explanation would not satisfy the minimal requirement and could not be a legitimate mechanistic explanation.

6. Conclusion

The analytical sociology's initial position regarding components of social mechanisms in explanations of social macro-phenomena is that they must be individuals, their properties, actions, and relations to one another. After the critiques against this approach, different answers have been raised by analytical sociologists. Schmid (2011) has formulated a new argument in support of that initial position, while Ylikoski (2012) has proposed a perspectival version of it. Nevertheless, both proposals face outstanding difficulties. The analytical sociology's initial position regarding components of social mechanisms should be given up. There is no privileged level to which components of social mechanisms in mechanistic explanations of social macro-phenomenon must always belong. However, a minimal requirement can be raised with respect to components of social mechanisms, that is, components of social mechanisms in mechanistic explanations of social macro-phenomena must not have the *explanandum* phenomenon as a part.

The proposed minimal requirement would considerably contribute to the development of the mechanistic account of scientific explanation in social science. Firstly, it offers a unified and justified response to the question of components. In all mechanism-based explanations of social macro-phenomena, components of social mechanisms must satisfy the proposed requirement. Secondly, the adoption of the minimal requirement would make the mechanistic account less narrow and able to account for a greater number of legitimate explanations. This would aid to actualize its will of broad applicability. As it has been noted, the mechanistic account aims to be broader than previous proposals (e.g. covering-law model) and suit many legitimate explanations that are excluded by them. And thirdly, the proposed minimal requirement provides a framework within which more specific non-individualist approaches to mechanism-based explanations in social science could be developed. For example, it could assist the elaboration of actor-based approaches to causal mechanistic explanations (e.g. Ruonavaara 2012). Those approaches are based on the idea that causal mechanistic explanations (especially when the *explanandum* is an interdependency between social phenomena) have to be in terms of actors, which do not need to be individuals, and their actions and interactions. Examples of actors would be firms, residents, and political parties.

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Mechanisms and science denialism: explaining the global lung cancer epidemic

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ABSTRACT

Explanation is one of the main aims of science. Scientists frequently seek to explain scientific phenomena. This paper addresses the relationship between scientific explanation and science denialism. In it, explanatory wars are introduced. An explanatory war is a situation in which the standard scientific explanation of a phenomenon is systematically denied by a group of people. It is argued that the mechanistic account of scientific explanation is helpful in order to face this kind of science denialism. Mechanistic explanations are resistant to the arguments usually raised by denialists. The relevant role of mechanistic explanations is illustrated by the case of tobacco disease denialism during the second half of twentieth century.

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Mechanisms and science denialism: explaining the global lung cancer epidemic

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§1. Introduction

EXPLANATION IS ONE OF THE MAIN AIMS of science. As Ylikoski accurately claims, science could be considered "the business of explaining things" (2013, p. 277). Scientists frequently seek to explain scientific phenomena. The explananda can be regularities (e.g. the movement of planets), events (e.g. the cracking of a car radiator) or properties (e.g. the hardness of diamonds). The central role of explanation in science has not gone unnoticed by philosophers. Scientific explanation has been a subject of philosophical reflection since Pre–Socratic times —although the modern discussion began with the development of the covering–law model (Hempel 1965). Philosophers of science have not only discussed the nature of scientific explanation. They have also addressed related issues such as the notion of explanatory value, the relation between explanation and other epistemic goals (e.g. prediction), the role of models in explanation, etc.

The aim of this paper is to address the relationship between scientific explanation and science denialism. The structure of the paper is as follows. Section two analyses science denialism and introduces explanatory wars. An explanatory war is a situation in which the standard scientific explanation of a phenomenon is systematically denied by a group of people. Section three presents the mechanistic account of scientific explanation and argues that it is helpful in order to face explanatory wars. Mechanistic explanations are resistant to the arguments usually raised by denialists. Section four illustrates the relevance of mechanistic explanations to face explanatory wars by means of analysing a paradigmatic example (i.e. tobacco disease denialism during the second half of twentieth century). Finally, section five concludes.

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§ 2. Science denialism and explanatory wars

Two forms of pseudoscience have been identified: science denialism and pseudotheory promotion (Hansson 2017). While pseudotheory promotion's main aim is to promote a specific theory (e.g. homeopathy, i.e., the claim that a substance that causes certain symptoms in healthy people would in highly diluted form cure similar symptoms in sick people), science denialism is focused on denying certain scientific claims (e.g. Earth is warming because of greenhouse gas emissions). Science denialism consists in the systematic rejection of a claim on which a scientific consensus exists (Diethelm and Mckee 2009; Liu 2012; Hansson 2017). It is usually targeted at scientific claims that damage people's lifestyle or worldviews, or that threaten corporate interests (Lewandowsky *et al.* 2016). Some prominent examples of science denialism are tobacco disease denialism, evolution denialism, climate change denialism, holocaust denialism, aids denialism, and relativity theory denialism.

In spite of their dissimilarities, there are five epistemological characteristics that are present in all cases of science denialism (Liu 2012; Hansson 2017; 2018a). Firstly, cherry–picking of data is systematically employed in their argumentations. Only a small part of the available evidence in taken into account.[1] Secondly, refuted claims are not always given up. Denialists are reluctant to give up ideas and arguments even when they have been refuted. Thirdly, fake controversies are fabricated. It is claimed that a certain issue is subject to a genuine scientific controversy, although an overwhelming consensus exists among scientists. Fourthly, deviant criteria of assent are introduced. Denialists set unrealistic standards for evidence, which hardly can be met by current scientific research. And fifthly, the opposed viewpoint is misrepresented. The scientific claim is distorted by means of logical fallacies (e.g. the strawman fallacy), taking quotes out of context, focusing on what is unknown and ignoring what is known, etc.

There are also several sociological characteristics that are usually present in science denialism (Diethelm and Mckee 2009; Liu 2012; Hansson 2017; 2018a). Science denialism often has strong political connections (e.g. evolution denialism is related with Christian right wing) and is supported mostly by men. Its main advocates use to be fake experts who, although they may be competent in a certain field, are not qualified researchers in the pertinent area. Besides, denialists appeal to complex and secretive conspiracies to account for the

1 It should be noted that, although denialists often ignore unfavourable evidence, they could hardly ignore the target scientific claim itself. The main aim of scientific denialism is to undermine and deny that claim. Consequently, ignoring it would go against their own purposes.

scientific consensus on the denied claim and their inability to publish in mainstream peer–reviewed journals. Other sociological characteristics that are often present in science denialism are attacking individual scientists personally and professionally, pretending to have a significant support within science, and addressing laypeople instead of scholars.

Several characteristics of science denialism are also present in pseudotheory promotion (Hansson 2018a; 2018b). In both forms of pseudoscience, cherry–picking is used, refuted claims are not always given up, and criteria of assent almost impossible to satisfy are introduced. Other shared traits are: appealing to fake experts, directly addressing the public, and pretending to have a significant support within science. Nonetheless, there are relevant differences between science denialism and pseudotheory promotion. The main difference concerns their approaches to conflicts with genuine science (Hansson 2018a). Pseudotheory promotors tend to avoid conflicts with genuine science. To increase the acceptability of the promoted theory, they want to give the impression that it is compatible with mainstream science. However, science denialists have a conflict seeking attitude to genuine science. Their aim is to defeat a certain part of mainstream science, and opposing it is an important step to achieve that goal. Another relevant difference is that fabrication of fake controversies, which has an important role in science denialism, is not present in pseudotheory promotion (Hansson 2017). Furthermore, strong political connections, male dominance, and fierce attacks on individual scientists characterize science denialism, but not in general pseudotheory promotion.

It is important to note that science denialism is not a form of genuine scientific scepticism (Liu 2012; Prothero 2013; Lewandowsky *et al.* 2016). Scientific scepticism consists in not believing things just because someone claims them, but being cautious and test claims against evidence. If a claim is eventually widely supported by evidence, the sceptic must accept it. However, science denialism consists in being ideologically committed to reject a scientific claim. The denialist will hardly change their mind, whatever the evidence says. Furthermore, science denialism's characteristics such as fabricating fake controversies, invoking conspiracies, and personally and professionally attacking scientists, are not proper to genuine scientific scepticism. In fact, science denialism is a misrepresentation of scientific method.[2] As Rosenau explains, "[b]y dismissing the knowledge produced by scientific processes and

[2] Science denialism is not an anti–science movement (Rosenau 2012). Actually, it often presents itself as science in order to take advantage of the cultural and epistemic authority of science. Science denialists establish research institutions, launch journals, organize conferences, etc.

touting ideas that are untestable or have failed such tests, science denial misleads the public about how science works, opening the door to other pseudoscientific beliefs" (2012, p. 567).

A relevant kind of science denialism, which has not been previously addressed, is explanatory war. An *explanatory war* is a situation in which (i) there is an undisputed phenomenon (e.g. an increasing incidence of a disease), (ii) in the scientific community there is a broad consensus on its explanation, and (iii) the standard scientific explanation is systematically denied by a group of people. In this kind of science denialism, denialists do not question that the explanandum exists. It is accepted that certain phenomenon is the case and that it requires an explanation. However, they reject the explanans to which mainstream science appeals to account for the phenomenon. In order to fight down the mainstream science's explanation, two strategies are usually followed by denialists. On the one hand, they directly attack the standard explanation. For instance, they claim that the causal link between explanans and explanandum has not been proved with one hundred percent certainty (Proctor 2011; Prothero 2013). On the other hand, denialists propose and promote alternative explanations, which are presented as being as legitimate as the standard explanation, to increase the controversy and make their case more credible (Proctor 2004; Proctor 2011; Pearl and Mackenzie 2018).[3] For example, they support private research to study every minimally plausible alternative explanation. They also demand equal time and space in the media for alternative proposals (Hansson 2018a). In explanatory wars, science denialism's distinctive characteristics are present. For example, the introduction of deviant criteria of assent and the fabrication of fake controversies have a central role in the offensive against the standard explanation. Cherry–picking evidence is also relevant; denialists often ignore part of the evidence in support of the standard explanation.

A paradigmatic example of explanatory war is tobacco disease denialism during the second half of twentieth century (i.e. the tobacco wars) (Proctor 2011). In that period, it was generally accepted that the incidence of lung cancer had dramatically increased during the twentieth century. Furthermore, since the mid–1950s, there was a broad consensus among scientists that the increase in tobacco consumption accounted for this phenomenon (Proctor 2011; 2012). However, the tobacco industry systematically denied the standard

3 In explanatory wars, a certain form of pseudotheory promotion is often present. Denialists introduce and promote alternative explanations to increase the controversy. Nonetheless, this promotion has only a subsidiary relation to the denial of the standard explanation.

explanation of the lung cancer epidemic (Proctor 2011; Prothero 2013; Pearl and Mackenzie 2018). Although they accepted that the frequency of lung cancer had increased and that this required an explanation, they rejected the explanation that linked the lung cancer epidemic with their product. In order to fight down the standard explanation, the tobacco industry attacked it (e.g. it was argued that the statistical evidence that linked explanans and explanandum was not conclusive) and promoted alternative explanations (e.g. industrial air pollution is responsible for the lung cancer epidemic).

Science denialism is a form of pseudoscience whose main aim is to deny certain scientific claim. A particular kind of science denialism is explanatory war. An explanatory war is a situation in which the standard scientific explanation of a phenomenon is systematically denied by a group of people. This kind of explanatory denialism is especially relevant because it undermines one of the main aims of science, i.e., explaining phenomena, insofar as shared criteria concerning how good an explanation is are challenged. Furthermore, given the central role of explanation in understanding, it is prejudicial for the public understanding of science. In the following section, it will be argued that the mechanistic account of scientific explanation can help to face explanatory wars.

§ 3. The mechanistic account of scientific explanation

The mechanistic account of scientific explanation has recently been developed within the framework of the new mechanical philosophy (Machamer, Darden and Craver 2000; Bechtel and Abrahamsen 2005; Glennan 2017). Nevertheless, its main principles were previously proposed by authors such as Rom Harré (1972) and Wesley Salmon (1984). The mechanistic approach is based on the idea that a phenomenon is explained by means of identifying the mechanism that is responsible for it. Within the new mechanical philosophy, there is no consensus on the notion of mechanism (Hedström and Ylikoski 2010). Nonetheless, some basic aspects are shared by most proposals. A mechanism is usually characterized as an organized constellation of entities and activities (Machamer, Darden and Craver 2000; Glennan 2017). It is considered that a mechanism is always a mechanism for a phenomenon (Glennan 2017). The phenomenon for which a mechanism is responsible is the main reference for its identification, delimitation, and decomposition. New mechanists also agree that mechanisms are nested and form a hierarchy (Machamer, Darden and Craver 2000). A component of a mechanism is often a mechanism itself. For example, a heart is both a mechanism and a component of a mechanism (e.g. circulatory system).

Mechanistic explanations can be causal or constitutive (Ylikoski 2013). The relation between a mechanism and the phenomenon for which it is responsible may be causal or constitutive. Consequently, depending on the relation between the identified mechanism and the phenomenon of interest, an explanation is either a causal mechanistic explanation or a constitutive mechanistic explanation. Mechanistic explanations are often presented by means of mechanistic models. A mechanistic model has two components: a phenomenal description and a mechanistic description (Glennan 2017). The phenomenal description is a model of the phenomenon of interest, while the mechanistic description is a model of the mechanism responsible for that phenomenon. In this kind of explanations, the phenomenal description is (or represents) the explanandum and the mechanistic description is (or represents) the explanans (Glennan 2005).

An example of a mechanistic explanation is Schnitzer's (2005) explanation of global patterns of liana abundance and distribution. Unlikely trees and shrubs, lianas correlate negatively with annual precipitation. There is a higher abundance of lianas in forests with low precipitation and high seasonality than in aseasonal wet forests. Schnitzer explains that phenomenon by means of identifying the mechanism responsible for it, i.e., "the extensive root and efficient vascular systems of lianas" (Schnitzer 2005, p. 274). He argues that "[l]ianas have extremely deep and efficient root and vascular systems and thus may be able to tap water and nutrients that many trees and shrubs are unable to access during drought conditions" (Schnitzer 2005, p. 266). During dry seasons, because of their constant supply of water, lianas are not water stressed. They capitalize on solar radiation, which is more abundant in dry seasons, and grow more than trees and shrubs. Lianas' dry season growth advantage results in a high abundance of them in seasonal forests. However, in aseasonal wet forests, where water is rarely limiting, lianas cannot benefit from their dry season growth advantage. They face a fiercer competition from other plants. Consequently, lianas are less abundant in aseasonal wet forests.

Mechanistic explanations have been developed as an alternative to covering–law and statistical explanations (Salmon 1984; Hedström 2005). Covering–law and statistical explanations are "black–box explanations" (Hedström and Swedberg 1998). They connect initial conditions with final output by means of universal laws or statistical generalizations. However, the processes through which explanans and explanandum are actually linked are not addressed by them. They consider that the link between explanans and explanandum is devoid of structure or that its structure is explanatorily irrelevant. On the contrary, mechanistic explanations are "how–explanations". They show "how some phenomenon comes about" (Glennan 2017, p. 228). Mechanistic explanations open the black box between explanans and explanandum and detail the processes that give rise to the latter. The mechanistic account of scientific explanation also addresses other problematic aspects of covering–law and statistical approaches. One of the main problems of the covering–law model is its narrow scope (Scriven 1959). Given that few or no laws are known in several fields of science (e.g. sociology, biology, economics…), it has a very limited scope of application. Nevertheless, many mechanisms are often known in those fields where laws are not available. The mechanistic account of scientific explanation, which does not require laws, has a broader scope. It can be adopted in those fields where few or no laws are known. With regard to statistical explanations, their main problem is that "[s]tatistical regularities are rarely (if ever) as unequivocal and easily interpretable in causal terms as this view would seem to suggest" (Hedström 2005, p. 23). On the contrary, mechanisms do offer unequivocal information about causal relations (Steel 2004; 2008). On the positive side, from knowing the causal mechanism through which X influences Y, it can be inferred that X is a cause of Y. And on the negative side, if no plausible causal mechanism running from X to Y can be conceived, it can be concluded that X is not a cause of Y.

The mechanistic account of scientific explanation is helpful to face explanatory wars.[4] In an explanatory war, the standard scientific explanation of a phenomenon is denied by a group of people. Nonetheless, if the standard explanation is mechanistic, denialists' offensive is less effective. Mechanistic explanations are resistant to the arguments usually raised by denialists. In order to fight down the mainstream science's explanation, two strategies are followed by denialists. Firstly, they directly attack the standard explanation. Denialists' attacks often focus on arguing that the standard explanation does not satisfactorily prove the causal link between explanans and explanandum. For

[4] Mechanistic explanations are also relevant for public understanding of science (Lewandowsky and Oberauer 2016). Recent experimental studies show that a brief mechanistic explanation of global warming significantly increases climate change acceptance (Ranney and Clark 2016). Nonetheless, it should be noted that pseudoscience (particularly pseudotheory promotion) may also take advantage of the compelling nature of mechanistic explanations (for a real case, see Holman 2017). The seductive allure effect of mechanistic explanations holds even when the reductive information is logically irrelevant (Hopkins, Weisberg and Taylor 2016).

example, they claim that statistical methods are inadequate for identifying causal relations. Their arguments are based on "an extraordinarily narrow and mechanical conception of causation" (Proctor 2011, p. 275). Secondly, denialists propose and promote alternative explanations to increase the controversy. Alternative explanations usually rely on statistical correlations between the explanandum phenomenon and variables not included in the mainstream science's explanation (Proctor 2004; 2011). Those explanations are presented as being as legitimate as the denied standard explanation. However, the strategies followed by denialists are hardly effective against mechanistic explanations. On the one hand, mechanistic explanations prove the (causal or constitutive) link between explanans and explanandum. They show how the phenomenon of interest comes about. On the other hand, alternative explanations raised by denialists would not be legitimate explanations on the same footing than the standard explanation. They are rarely mechanistic explanations, but black–box explanations that do not address the link between explanans and explanandum, and are not supported by the same kind of evidence that supports standard mechanistic explanations.[5]

The mechanistic account of scientific explanation, which is based on the idea that a phenomenon is explained by means of identifying the mechanism that gives rise to it, is helpful to face explanatory wars. Mechanistic explanations are resistant to denialists' attacks. Consequently, if the standard explanation is mechanistic, denialism's offensive is less effective. In the next section, the relevant role of mechanistic explanations will be illustrated by analysing the explanatory war regarding the global lung cancer epidemic. In order to address that case, the work by the historian of science Robert Proctor (2001; 2004; 2006; 2011; 2012) will be taken as reference.

§ 4. The tobacco wars

At the beginning of the twentieth century, lung cancer was an extraordinarily rare disease (Proctor 2001; 2011; 2012). It was so uncommon that "[o]nly 140

[5] Denialists could, given the ease with which humans come up with mechanistic narratives, propose alternative mechanistic explanations with little actual evidence in favour. Nevertheless, it is doubtful that they could successfully use them against a standard mechanistic explanation. In order to increase the controversy and make their point more credible, denialists must propose alternative explanations that can be widely considered as legitimate as the standard explanation. However, hardly could alternative mechanistic explanations invented by denialists be considered as legitimate as the standard mechanistic explanation. They, unlike the standard explanation, would be neither supported by evidence of mechanisms nor compatible with the available evidence of mechanisms.

cases had been reported in the world medical literature by 1898, and only 374 were known to [Isaac] Adler when he composed his 1912 review" (Proctor 2001, p. 83). When a case was discovered, physicians were called to observe it because they may never see another (Proctor 2001). However, during the first decades of the twentieth century, an increased incidence of lung cancer was noted in several countries (e.g. USA, Germany…). The disease "began showing up more often, both clinically and at autopsy, prompting head scratching and, eventually, alarm" (Proctor 2004, p. 374). This dramatic change in the incidence of lung cancer begged for an explanation. Scientists started considering what might be responsible.

During the following decades, several possible explanations of the lung cancer epidemic were proposed. Among the diverse factors that were taken into account were atmospheric pollution, asphalt dust emissions from newly paved roads, occupational exposures, X–rays, genetic predispositions, poison gas from First World War, the 1918–1919 flu pandemic, aluminium dishware, the fashion of eating tomatoes, racial intermarriage, and the growing popularity of cigarettes (Proctor 2004; 2011). In that period, cigarettes were considered just one of many possible causes of the global lung cancer epidemic.

Nevertheless, during the 1950s, the idea that tobacco consumption explained the lung cancer epidemic took the lead (Proctor 2011). Experts in the field considered that smoking indeed caused lung cancer. The causal link between cigarettes and lung cancer was established by four distinct lines of evidence: population studies, animal experimentation, cellular pathology, and chemical analytics (Proctor 2012). Scientific agreement regarding the causal relationship between smoking and lung cancer was expressed "in medial editorials, reviews, and textbooks; in annual reports of medical associations; and in 'white papers' and resolutions issued by public health authorities" (Proctor 2011, p. 232). As a result of this causal knowledge, a broad consensus emerged among experts that tobacco consumption accounted for the global lung cancer epidemic (Proctor 2011; 2012). It was widely considered that the growing popularity of cigarettes explained the high incidence of lung cancer.

By the mid–1950s, there was a consensus among scientists that tobacco consumption explained the lung cancer epidemic. However, the tobacco industry systematically denied that explanation. They admitted that the frequency of lung cancer had increased and that it required an explanation, but they rejected the explanation that linked the lung cancer epidemic to tobacco consumption. Part of the diverse evidence in support of the standard explanation was ignored by them, although this did not suffice to significantly threaten it (Proctor 2011). In order to fight down the explanation of mainstream science, the tobacco industry followed two strategies. Firstly, they directly attacked the standard explanation. Their main argument was that the causal link between tobacco and lung cancer was not conclusively established and more research was needed (Proctor 2011). They adopted a narrow and mechanistic account of causality and "developed an elaborate strategy by which each new proof of a hazard would be met by insinuations of doubt and calls for endlessly more research" (Proctor 2004, p. 374). Despite the broad consensus in the scientific community, the tobacco industry claimed that the case was not yet closed and that it would be dangerous to hastily jump to conclusions. A great part of their efforts focused on undermining the statistical evidence that linked tobacco consumption to lung cancer (Pearl and Mackenzie 2018). For example, in "A Frank Statement to Cigarette Smokers" (1954), it was argued that "statistics purporting to link cigarette smoking with the disease could apply with equal force to any one of many other aspects of modern life".[6] Secondly, the tobacco industry promoted alternative explanations of the global lung cancer epidemic (Proctor 2004; 2011). By means of bodies such as the Tobacco Industry Research Committee (renamed as Council for Tobacco Research in 1964) and the Tobacco Institute, they funded and publicised research focused on investigating possible causes of lung cancer other than tobacco (e.g. stress, pesticides, industrial air pollution…). As Proctor claims, "'open controversy' was a key pillar in the industry's conspiracy, and the CTR [Council for Tobacco Research] always professed its 'openness' to alternate hypotheses when it came to disease causation" (2011, p. 273). A well–known alternative explanation publicised by the tobacco industry was that a "smoking gene" both caused people to smoke cigarettes and made them more likely to develop lung cancer (Fisher 1957; 1958).

6 "A Frank Statement to Cigarette Smokers" is a full–page advertisement by the Tobacco Industry Research Committee that was published in 448 US newspapers on January 4, 1954. It marked the beginning of tobacco industry's denialist approach (Proctor 2011).

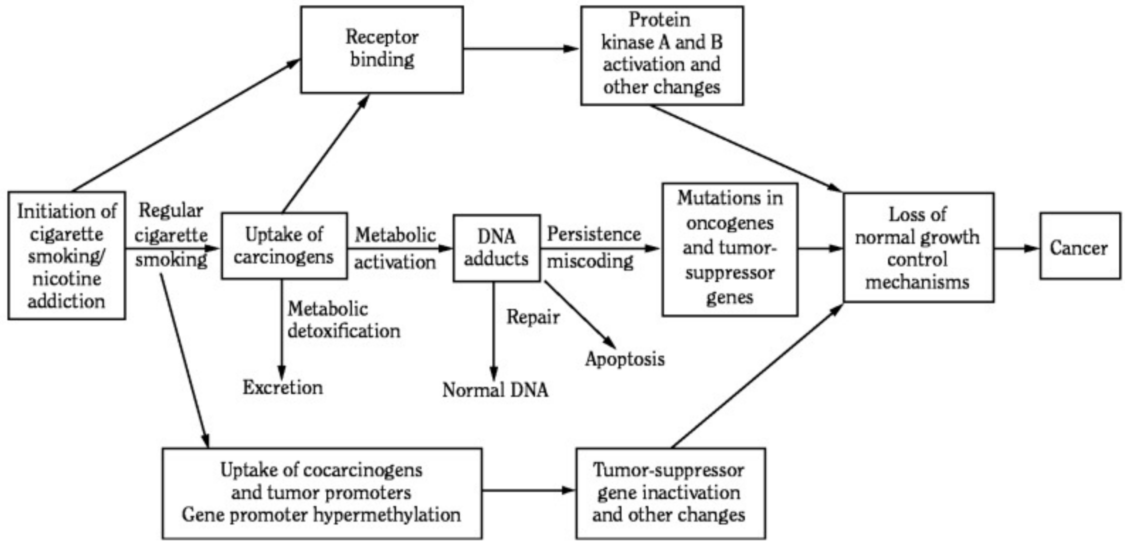

Figure 1. Link between cigarette smoking and cancer through carcinogens in tobacco smoke (U.S. Department of Health and Human Service 2010).

In the 1990s, the mechanisms through which smoking causes lung cancer were discovered (Proctor 2001). For instance, Denissenko *et al.* (1996) provided "a direct link between a defined cigarette smoke carcinogen and human cancer mutations" (1996, p. 274). Mainstream science's explanation of the lung cancer epidemic became a causal mechanistic explanation (Russo and Williamson 2007). It detailed the mechanisms through which smoking brings about lung cancer (see figure 1). At the same time, there was a radical change in the tobacco industry's approach (Proctor 2001; 2006; 2011). They stopped denying the standard explanation of the global lung cancer epidemic. They accepted that tobacco was a risk factor in the development of lung cancer and that tobacco consumption accounted for the high incidence of lung cancer. This change has been evidenced in trials against tobacco companies (Proctor 2001; 2006; 2011). Their legal strategy is not anymore denying the causal link between smoking and lung cancer, but arguing "that the risks of smoking have been well–known for decades, and that people therefore voluntarily assume such risks when they take up the habit" (Proctor 2001, p. 84). Historians of medicine are hired by tobacco companies to "re–narrate the past, creating an account for judges and juries that make it appear that 'everyone has always known' that cigarettes are harmful" (Proctor 2006, p. iv117). Historians hired by tobacco companies also argue that there was no conclusive evidence that cigarettes are harmful until quite late, thereby justifying industry's extreme caution to accept cigarettes' hazards.

Tobacco denialism during the second half of twentieth century is a representative case of explanatory war (see section 2). It was generally accepted that the incidence of lung cancer had dramatically increased during the twentieth century and there was a broad consensus among scientists that tobacco consumption accounted for that phenomenon. However, the tobacco industry systematically denied the standard explanation of the lung cancer epidemic. This paradigmatic example of an explanatory war illustrates the relevance of mechanistic explanations to face them.

From the mid–1950s to the 1990s, the standard scientific explanation of the global lung cancer epidemic was not mechanistic. It was a non–mechanistic causal explanation based on statistical evidence (Russo and Williamson 2007). During that period, the tobacco industry denied the standard explanation. They followed two strategies to undermine it. Firstly, they claimed that it was not a satisfactory explanation. They argued that it did not conclusively establish the causal link between smoking and lung cancer. Statistical evidence was considered insufficient for supporting a causal claim. Secondly, the tobacco industry promoted alternative explanations (e.g. the "smoking gene" explanation), which were presented as being as legitimate as the standard explanation. They were compatible with the available evidence. Furthermore, many of them were supported by the same kind of evidence as the explanation used in mainstream science (i.e. statistical evidence).[7]

In the 1990s, however, the standard explanation of the global lung cancer epidemic became mechanistic. It detailed the mechanisms through which smoking brings about lung cancer. Consequently, the tobacco industry's strategies against mainstream science lost their effectiveness. On the one hand, the standard explanation conclusively established the causal link between smoking and lung cancer. It suited the narrow mechanistic account of causality adopted by denialists and made the "more research" argument obsolete. On the other hand, the standard explanation clearly distinguished itself from the alternative explanations promoted by denialists. It was a causal mechanistic explanation, while the alternatives were statistical or non–mechanistic causal explanations (i.e. black–box explanations). They were not supported by the same kind of evidence either. The standard explanation was supported both by

7 Several scientific studies, most of which were funded by the tobacco industry, offered statistical evidence in support of alternative explanations (Proctor 2011). For example, Wynder and Hammond (1962) presented statistical evidence linking general air pollutants to the development of lung cancer, and Hickey, Boyce, Harner, and Clelland (1970) identified a significant statistical correlation between certain environmental chemicals and lung cancer.

statistical evidence and evidence of mechanisms, but alternative explanations were at best supported only by statistical evidence. They did not suit the available evidence of mechanisms. Finally, in the 1990s, the tobacco industry changed its approach and stopped denying the standard explanation of the lung cancer epidemic. They accepted that tobacco was a risk factor in the development of lung cancer and that tobacco consumption explained the high incidence of lung cancer.

Tobacco disease denialism during the second half of the twentieth century is a paradigmatic example of an explanatory war. This case illustrates how the mechanistic account of scientific explanation is helpful to face this kind of science denialism. In the 1990s, mainstream science's explanation of the global lung cancer epidemic became a causal mechanistic explanation. This change made it more resistant to denialists' attacks. It satisfied denialists' demanding requirements (e.g. the mechanistic account of causality) and distinguished itself from the alternative explanations promoted by denialists. This resistance undermined the denialists' approach and, ultimately, influenced them to admit to the standard explanation.

§ 5. Conclusion

Science denialism is a form of pseudoscience. Unlike pseudotheory promotion, it does not focus on promoting a specific theory (e.g. homeopathy). Science denialism consists in the systematical rejection of a claim on which scientific consensus exists. A relevant kind of science denialism is explanatory war. An explanatory war is a situation in which (i) there is an undisputed phenomenon, (ii) in the scientific community there is a broad consensus on its explanation, and (iii) the standard scientific explanation is systematically denied by a group of people. The mechanistic account of scientific explanation is helpful to face explanatory wars. Mechanistic explanations are resistant to the arguments usually raised by denialists. Tobacco disease denialism during the second half of twentieth century, which is a paradigmatic example of an explanatory war, illustrates the relevant role of mechanistic explanations.

It should be noted that this does not imply that explanatory wars are unavoidably doomed to failure when the standard scientific explanation is mechanistic. Standard mechanistic explanations are resistant to denialists' usual attacks. However, it does not mean that they are completely immune to any possible denialists' offensive. In fact, there are cases of science denialism (although of a different kind than explanatory wars) in which it remains moderately active despite the target scientific claim being mechanistic (e.g.

AIDS denialism). Nerveless, what kinds of critiques and attacks could still be effective against standard mechanistic explanations is a question that exceeds the scope of this paper.

Several benefits of mechanistic explanations have been identified previously. They increase public understanding of science, connect different ontological levels, offer helpful possibilities of representation, do not require covering–laws... In addition, as it has been argued through this paper, they are also helpful to face a certain kind of science denialism, i.e., an explanatory war. Mechanistic explanations are more resistant to denialists' offensives than other kinds of explanations (e.g. statistical explanations). Consequently, adopting a mechanistic account of explanation is a useful tool for dealing with science denialism. Mechanistic explanations should be encouraged in those areas of science where science denialism is a major problem.

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