Technology, nature's appropriation and capital accumulation in modern agriculture /// Tecnología, apropiación de la naturaleza y acumulación de capital en la agricultura moderna

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Technology, nature's appropriation and capital accumulation in modern agriculture

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Framed by efficiency and productivity narratives, technological innovations are conceived as the inexorable pathway to agricultural development, obscuring the associated appropriation of ecological surpluses and depletion of natural resources. In the past two decades, increasing food, energy and animal feed global demands, have hasted capitalization, pushing the exhaustion of ecosystems to new thresholds that compromise the ecological bases of capital accumulation. Likewise, the hegemonic technological-led path of development is confronted by political contestation and competing framings. Here we aim to understand how current technological innovations address the questioning of agriculture's sustainability. We are interested both on the solutions that are put forward to expand capital accumulation and on the narratives that allow to recast and legitimate actors and processes in industrial agriculture.

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Introduction

During the last two decades, agricultural production has witnessed a remarkable growth. Linked to the so-called Biotechnological Revolution, technological innovations have not only pursued productivity enhancement, but have also been a key tool in the expansion of agricultural frontiers [1] and major land use changes. Framed by efficiency and development narratives according to which agricultural expansion and productivity gains basically result from technological innovations, the appropriation of ecological surpluses[1] that these innovations help to deliver are overshadowed [2••].

Capital accumulation rests upon a contradictory dialectic of productivity and plunder. It needs to extend the realm of nature's *free gifts* that can be appropriated in order to reproduce and expand accumulation while, at the same time, the enhanced capitalization of nature (that is the portions of nature that are reproduced under the circuit and logics of capital, e.g. gene editing, robotic milking, transgenic seeds, pesticides and fertilizers) increasingly depletes the biophysical basis of agricultural production [3].

At the core of this dialectic stands the mediating role of technological innovations in capitalist agricultures: the development of procedures, mechanisms, devices and organizational schemes to achieve yield leaps and to widen capital's reach over under and un-capitalized nature. It is precisely in those under and un-capitalized territories where the ratio between capital investment and economic gains is higher.

Multiple and convergent crises (food, energy and financial) since mid-2000′s have hasted a global rush for land [4–7], drawing vast territories into the matrix of accumulation. The global land rush has pushed inequalities, exclusions, depletion and pollution of soils, water and ecosystems to new thresholds [8]. In this context, previously masked 'costs' of industrial agriculture are being increasingly internalized by farmers through the use of industrial inputs, as a consequence of the deterioration of the productive conditions (e.g. the use of fertilizers to cope with soil nutrients depletion) [2••], compromising the ecological bases upon which capital accumulation rests and making profit gains more unstable. Likewise, the hegemonic productivity and market-led path of development are confronted by political contestation and competing framings [9••].

[1] We refer to capital's capacity – through the development of technological innovations, social patterns of organization and governance – to appropriate increasing amounts of biophysical and human natures at low costs. Along the history of agriculture, technological revolutions have enabled relatively small amounts of capital to launch a huge mass of use-values. However, ecological surpluses are partially produced through socio-technical innovations; rather they are delivered through their combination with the appropriation of biophysical natures formed along geological times (i.e. water from aquifers) [3].

It is in this conjuncture that we aim to understand how current technological innovations are addressing the questioning of contemporary capitalist agriculture's sustainability. We are interested both on the type of solutions that are put forward in order to sustain/extend capital accumulation and on the narratives that allow to recast and legitimate actors and processes in industrial agriculture. As we will propose, this new assembling is not a mere response; it embodies a way of shaping 'sustainable agriculture'. We draw on scholarship from critical agrarian studies and politics that pay attention to the relationship between industrial agriculture and ecological crisis; this literature has contributed to better interrogate and problematize, both theoretically and historically, the weakness of materialist conceptions of productive forces in capitalist agriculture by incorporating perspectives from the field of political ecology [10].

Box 1 New technologies for modern agriculture

There is a burgeoning literature on new technological approaches to industrial agriculture. Precision agriculture [53•], climate smart agriculture [54], digital farming [55], smart farming [56], sustainable intensification [57], and agriculture 4.0 [58], are among the most relevant ones. Here we focus on the two types that have gathered more attention during the last years.

Precision agriculture

Precision agriculture (PA) refers to 'techniques that monitor and optimize production processes by advising farmers and/or remotely adjusting machinery to optimally apply fertilizers or chemicals to the land and feed to animals, thereby conceivably increasing yields and outputs and improving the efficiency and effectiveness of inputs' [29••]. Using farm inputs more efficiently, PA promises to sustain or increase yields, lessen environmental impacts [59], contribute to food security [60] and consolidate a pathway towards environmental sustainability [61]. PA also permits the traceability of farm products which allows meeting the growing demands of supermarkets chains [29••,30•].

PA relies on a bundle of interconnected technologies [53•] such as GPS, satellite images, robotics, environmental sensors, intelligent-farm machinery, internet of things, data-transmission devices, complex algorithms and cloud computing. The common thread among them is the handling of huge amounts of data in order to turn them into near real-time advice to farmers.

Big data are the backbone of PA [62] and some authors describe it as 'the new cash crop' [29••]. To put it in perspective, the average farm in the US is expected to generate an average of 4.1 million data points per day by 2050, up from 190 000 in 2014 [63]. PA has also gathered great attention from investors and financial markets [64] since it has a potential market value estimated in US$ 6 billion by 2021 [62].

The rapid expansion of PA has witnessed the emergence of new players: the AgTech companies. After detecting a technological niche or a new business opportunity that could be of farmers' interest, AgTechs mine, classify, analyze, and repackage data into the form of new technological products or services which are offered to targeted farmers. Large transnational companies have also entered into this business, developing their own digital technologies, or buying out promising or strategic AgTech companies [65].

For PA's advocates, this approach is called to revolutionize modern agriculture [66]. However, others argue that PA is not more than the intensification of mainstream agriculture; presented as a radical breakthrough, it is based on narratives that seek to normalize and legitimize the industrial production of agricultural commodities [30•]. Critics point out that PA disregards socioeconomic and environmental heterogeneities and power asymmetries among actors, and majorly mirror the interest of large-scale firms. Issues of data grabbing, copyright and technology access are central to current debates on PA [29••,64].

Climate smart agriculture

The concept of Climate Smart Agriculture (CSA) was introduced by FAO in 2010 [25], but gained momentum after the 21st Conference of the Parties (COP 21) held in Paris in 2015 [8]. FAO defines CSA as an 'agriculture that sustainably increases productivity, fosters resilience, reduces greenhouse gases, and enhances achievement of national food security and development goals' [67]. CSA has been described as a 'triple win' approach [68] that simultaneously addresses three major goals: increased adaptation to climate change, mitigation of climate change, and attainment of global food security [69–71]. CSA is also connected to the development of international carbon offset markets, which may become a major financing source for this kind of agriculture [72].

CSA does not promote nor ban any specific technological practices, as long as they foster efficiency, improve productivity and contribute to the above mentioned goals. CSA includes a wide range of practices such as zero or minimum tillage, crop rotation and intercropping, mulching, water management, efficient use of pesticides and mineral or organic fertilizers, the use of high quality seed varieties, feed efficiency, and improved grazing and livestock management [72,73]. The World Bank in its Climate Change Knowledge Portal presents a series of countries' agriculture profiles identifying CSA technologies for each of the listed countries. For instance, in the case of Argentina it identifies no-tillage and the precise use of fertilizers and pesticides as major CSA technologies [74].

CSA puts forward debates on the substitutability between natural and physical capital [75], and its social and environmental impacts [76]. CSA approach is not only criticized because it does not exclude the use of industrial inputs nor GMOs, but also because it favours a top-down transfer-of-technology model controlled at large by transnational companies [72,11••]. This approach to agriculture does not confront current political agendas and minimize key issues concerning power, inequality and access. La Via Campesina disputes the CSA framework and suggests that it is a facade that allows an increasing corporatisation of global agriculture [38].

PA and CSA aim for a more efficient and environmental friendly agriculture that enhances productivity, while increasing resilience, reducing greenhouse gas emissions and fostering food security [53•,54]. They rest upon a set of principles and technological practices that aim to tackle the main criticisms raised against industrial agriculture. However, critics suggest that both approaches have a productivist focus that fails to address the social-environmental contradictions which have characterized the last 50 years of agricultural intensification, and to alleviate poverty and inequality [35,38,68,77•].

Box 2 Models of technological transfer

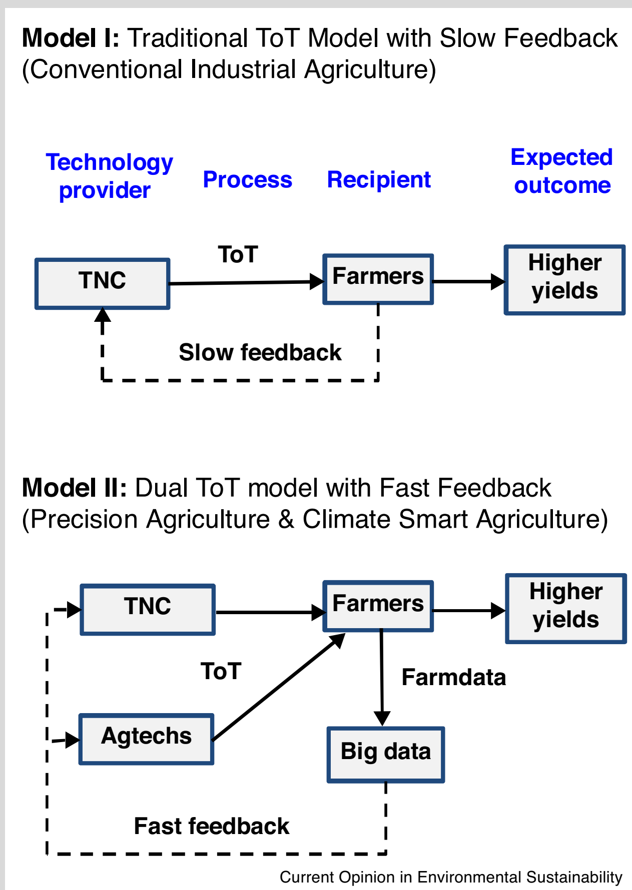
During decades, industrial agriculture has been based on the Diffusion of Innovations Model proposed by Rogers [78], which considered farmers as rational actors making independent decisions [79]. Although there are several models that explain how farmers innovate and adopt technologies [53•], the underlying overall process follows a transfer of technology model (ToT) where technologies are both produced and delivered by large companies to farmers following a top-down logic (Model I).

During several decades transnational companies supplying machinery and inputs were the main players in the ToT arena. But recently AgTech companies have entered the game to occupy a technological niche closely linked to precision agriculture (Model II). AgTechs aim to transform the huge amounts of data generated by modern agriculture into new agricultural products or services. Unlike the technologies developed by large agribusiness companies that focus on 'tangible' products, AgTechs deliver information through data mining and processing, a 'non tangible' product which allows a 'tailored' advice to farmers [29••]. Noteworthy, AgTechs entered technology markets following a strategy less dependent on big capital and large companies' commercial networks. Instead, and drawing upon communication technologies, they focus on data, knowledge and services.

Large agribusiness companies are also taking part of this new market. In order to maintain or improve their dominant position, it is not uncommon for them to buy out promising or competing AgTechs [65]. Even when the overall model still flows top-down and is mostly unidirectional, the feedback from farmers to companies runs at a much faster pace (Table I).

It is worth pointing out that Model II has not replaced Model I. Both coexist and the second one complements and continuously feedbacks on the first. But, the Big Data component of Model II has profoundly changed the essence of ToT processes, since it is able to show in almost real-time how farmers' interests and needs are moving. This provides crucial information relative to markets' dynamics and, ultimately, contributes to adjust the strategies of capital accumulation followed by technology providers [29••].

Model I and Model II



Two models or transfer of technology (ToT). TNC: transnational companies.
Source: based on Ref. [29••].

The following section discusses technological changes which, guided by the need to address environmental issues, are articulated as smart-innovations. We explore its logics and focus on how technological transfer helps fostering the adoption of 'smart agriculture' approaches. We then turn to the narratives that enable a depoliticized framing through which technologies are reassessed and legitimated as beneficial for society as a whole.

In what direction is modern technology moving?

The entanglement of the various issues mentioned above defines the contours of present technological changes. Generically defined as *smart*, these technologies show how industrial agriculture tenets are rearticulated as a more rational and efficient way of farming that can mitigate biophysical and ecological problems as well as adapt to climate change. Productivity, efficiency, adaptation and mitigation are major pillars of this technological approach to agriculture (Box 1).

This approach acknowledges some of the criticisms to the 'costs' of industrial agriculture — there even are initiatives that include agro-ecological tenets and practices [11••]. But the technologies advanced by this approach should not be understood as only addressed to political contestations on environmental, agrarian and/or food issues [12,13]; they can also be seen as attempts to sustain capital accumulation and profit-making in a context of increasing sources of instability linked to biophysical deterioration [14].

The case of GM crops (e.g. soy and maize) clearly shows how current technological changes are conjured as urgent and strategic to achieve both sustainability and economic efficiency goals. On the one hand, GM agriculture is a particularly contested arena [15,16], where contrasting positions are observed [17–22]. On the other hand, the occurrence of herbicide-resistant weeds has rocketed during the last decade [23], and insect resistance to insecticides and to *bt* transgenic crops is rising [24]. Also, there are growing soil-fertility problems related to crop monocultures and soil-nutrients depletion [25]. Within the technological approaches nowadays in vogue – such as precision agriculture (PA) or climate smart agriculture (CSA) –, these problems are still tackled using agrochemicals (Box 1). Moreover, their declared efficient use of inputs may imply higher dozes, or pesticides mixtures [26]. Thus, the solutions put forward under the label of sustainability reinforce the logics of industrial agriculture [27]. Basically reliant on new (and unstable) fixes [14], these solutions increase farmers' dependence on technological developers and accelerate a technological treadmill, with farmers getting into an endless innovation/adoption loop that resorts to the same type of technologies that generated the problems they aim to solve [2••].

Besides entailing higher productive costs, smart technological approaches demand a more intensive, complex, and 'tailored' farm management [28,2••], changing the ways in which technologies are developed and delivered to farmers. These are significant features of smart-technological approaches that are reshaping pre-existing models of technological transfer (Box 2). In accordance with information technologies, they are connected to new forms of control over agricultural production, via data grabbing [29••].

Despite their alleged benefits in building a more efficient, environmentally friendly and sustainable agriculture, PA or CSA have not clearly achieved these goals (Box 1). As Weis points out, the celebrated efficiency of modern industrial agriculture depends on ignored and externalized costs to environment and society [14]. Rather than being efficient at reaching sustainable outcomes, this approach reinforces the basic logic of industrial agriculture: the use of nature both as a source of potential benefits that can be appropriated through capitalization and as a site for dumping wastes and pollutants (Box 3). Thus, PA, CSA and technologies alike are nothing but the intensification of industrial agriculture that goes alongside global neoliberalism [30•]. These technologies run in the frame of a global system of power and capital that is hungry for cheap and un-commoditized natures that are appropriated for free, or at low cost, by dominant actors [31]. But, as happened before, not every farmer is able to reap the benefits of technological transformations. New technologies demand large scales and foster economic concentration, differentiation and exclusion among farmers [28] whereas they open new business opportunities to firms providing inputs, machinery and/or data mining.

In short, technologies are central to make nature accessible and usable for capital, since they embody the capacity

Table I

Main differences between two models of transfer of technology (ToT). Model I: Traditional ToT model with slow feedback; Model II: Dual ToT model with fast feedback

Model I	Model II
Unidirectional/top-down	Unidirectional/top-down, but dual
From a model dominated by the transference of inputs and machinery . . .	. . . towards a model governed by highly elaborated data transfer for decision making and management
Large companies control the supply of inputs and machinery	Twofold strategy: (a) Large companies continue supplying inputs and machinery; (b) AgTechs use big data to generate new products and services largely based on knowledge
Focus on hardware products (tangible) for farming	Focus on software products (intangible) for decision making and management
Slow feedback	Fast feedback
Conventional industrial agriculture	Precision agriculture

Box 3 Nature as source and dump

It is business, rather than food production, what drives current industrial agriculture: the continuous search for the highest profit rates and the development of new business opportunities [33,80,81]. Drawing upon this logic, nature plays the double role of source and dump [82]. On the one hand, it is seen as a limitless supplier of those materials and processes which are necessary for agricultural production (e.g. soil fertility, water, pollination); on the other hand, as a dumping place where to dispose the 'externalities' that occur along production (e.g. soil depletion, contamination, biodiversity loss, GHG) and natural resources that, although important, are not compatible with short-term profit maximization (e.g. to remove and burn native forests for sowing annual crops). This duality has become the trademark of nowadays industrial agriculture, being source and dump two necessary sides of the same coin.

The social and environmental impacts of this logic can be observed at various scales. While agricultural 'mining' of natural resources happens at local or national scale, the disposal may occur both at local and global scale. Climate change is probably the best example of the latter and of how agricultural intensification has turned the atmosphere as the ultimate dumping frontier. Sourcing and dumping are coupled strategies that use horizontal and vertical frontiers (e.g. the expansion of agricultural frontiers over native ecosystems in the first case, and extraction of water from aquifers or metals from rocks' minerals in the second) and, at the same time, grasp key resources and get rid of externalities [3,83]. This strategy allows transferring nature's richness to the private domain while externalizing some of the negative impacts to society.

From this perspective, nature has a mere utilitarian role. It rests upon a Cartesian dualism that sees nature and society as independent entities, ignoring the fact that nature and society are deeply interwoven and historically co-produced. Society does not only act upon nature, it develops through the web of life [82]. Nature is seen as something that has to be controlled and dominated to satisfy human needs. Thus, interactions between nature and societies are built upon a rationale that justifies and normalizes nature's appropriation, exploitation and, ultimately, its destruction. [84,85].

But not only societies are detached from nature; farmers are also being separated from farming. The Tayloristic approach that characterizes today's agriculture breaks down the integrality of farming processes into a series of discrete tasks or productive steps, such as chemical fallow treatments, sowing, pest control, and harvest [12]. Frequently, these activities are outsourced, further contributing to farmers' separation from farming itself. Consequently, rather than being directly involved with productive issues, farmers increasingly assume a managerial role in order to deal with farm contractors [86], develop financial strategies, and/or seek new business opportunities [28]. The simplification, standardization and mechanization that industrial agriculture entails [14] make this separation more feasible. Modern technology also becomes an efficient tool to subordinate nature and appropriate its benefits.

of science to turn it 'legible', knowledgeable and measurable for capital [32••]. They are part of a larger assemblage of devices, practices, relations and ideologies that co-produces a specific way of conceiving nature as well as of establishing its uses and values and the acceptable 'costs' of human activity. The logic and dynamic of this co-production are shaped and governed by power and interests [33,27], and legitimated through discourses and narratives.

Going smart: narratives of technological change

In the last few years, a growing body of critical agrarian and environmental literature has called attention on a series of issues which have not been fully acknowledged by those advancing technology-based approaches – such as SCA or PA – to sustainability questions [27]. In general terms, this literature points to the narratives and framings that have nourished the rapid expansion and increasing adoption of these innovations, notwithstanding their ambiguous outcomes. Narratives are a key element of sustainability politics that set and shape the meanings of sustainability, the causes of environmental and ecological problems, the consequences of the intensification of agricultural production, and the solutions to better cope with them [34••,35,36]. Narratives are thus essentially involved in the operation of hegemony [37], obscuring critiques that challenge the dominant organization of agri-food systems, while showing that with the proper tunings it can duly deal with environmental issues [11••,38,9••]. As socio-political constructs, narratives are unstable and contested, and therefore entail a constant work of legitimation. Narratives assemble social values, beliefs and wonders, scientific and expert knowledge, contributing to normalize, enforce, confront or dispute a given state of things; they include both discursive and material practices through which actors are enrolled in a certain way of conceiving and addressing problems related to agricultural expansion and sustainability [34••,39].

Dominant narratives make use of powerful images to frame society's perception of what is presently at stake. Undoubtedly, the most common one is that of scarcity [34••]. Combining theories, ideas and figures on pressures induced by population growth and natural resource depletion [37] which in a more or less nuanced way preannounce a catastrophic future, scarcity narratives call for the *urgent need* of responses [40]. Strategic to the building of environmental politics, they simplify and overshadow the connections among heterogeneous elements related to the environmental threats posed by industrial agriculture, the actors who are in power to solve them and the types of knowledge to support them [35].

Mainstream narratives portray scarcity not as absolute but as relative to how resources are used [34••]; in other words, as a matter of technical solution [41,38]. In these narratives, the existing boundaries for the growth of agricultural production can be transformed through technological innovation. Presented as a 'new' approach, its logic is basically focused on technological fixes to production [2••,42–44]. From this perspective, the problems created by the use of technologies (i.e. agro-inputs, mechanization) can be overridden by 'smart' adjustments of existing technological fixes. Protocols on Good Agricultural Practices exemplify this logic by emphasizing on procedures at farm levels rather than on the type of technologies used [26].

Another narrative that organizes technology-led responses is that of the 'innovator' [45]: a farmer who is always ready to adopt cutting-edge technologies and takes well-informed risks. This narrative fruitfully masks the mechanisms which allow powerful agribusiness actors – agrochemical companies, food processors, exporters – to exert control over farmers' technological innovation pathways. These mechanisms have a disciplinary force, summoning farmers' acceptance and adoption of specific technologies as an own-made decision [46]. Acceptance goes far beyond the materiality of technologies; it conveys the search of productivity and profit improvement as a goal, thus recreating the ideological role of techno-scientific norms [47].

But technological innovations do not go alone: governance comes under the umbrella of *urgent need* solutions, mainly targeted at enhancing market access [11••,41,8]. However obvious, it is worth recalling that the linkages between technological and market-led changes are built by specific coordinates of knowledge, and inscribed in power. As Foucault [40] points out, at the core of these coordinates are power relations. In this sense, Karlsoon *et al.* [35] argue that smart agricultural initiatives should be understood as a political project linked to corporations that dominate food and fuel production and distribution. Likewise, Clapp *et al.* [27] call the attention to technological and market changes driven by 'smarter' forms of agriculture which lever up new business opportunities and open up new accumulation sites. This greatly occurs by engaging finance capitals in business projects and the creation of financial services and assets such as weather derivatives, carbon emission trading or crop insurance [48,49]. Thus, smart-technology solutions to environmental changes are part of major initiatives to surpass the crisis of legitimation of the hegemonic global model of agricultural production and consumption, and the barriers to accumulation posed by environmental changes [11••].

However, as Foucault also states, power relations legitimate and condition to the same degree, certain types of knowledge, while excluding others. From this perspective, sidelined or excluded issues have increasingly become battlegrounds of different and alternative visions on agricultural sustainability [38]. At the crux of these questionings is the lack or inadequate reflection on the uneven impacts of the scaling-up of industrial food markets and intensive technologies between countries and social groups (both in terms of class, ethnicity and gender) [27]; the minimization of equity issues related to who and how benefits from technological and market-led changes [35,50,51].

Concluding remarks

Concerns over the depletion of natural resources are not new. Neither are the accumulation crisis associated to decreasing productivity, nor the technological revolutions and fixes through which the inherent contradictions of capital accumulation have been (unsustainably) overridden [3]. Notwithstanding technology-led solutions are reinforced. This reinforcement occurs within two trends: the increasing dominance and scope of markets and a new balance between capital, labour and state [52]. From this perspective, making sense of technological changes requires considering the broader dynamics of capitalist restructuring. In other words, agricultural technologies stem from power and interests in food systems, and are permanently re-invented in pursuance of profit maximization and accumulation.

Closely connected to, and driven by new information and communication technologies, smart and precision agricultural technologies draw upon a complex regime [11••] which knits the affinity between a new technology and a sustainable agriculture. As argued here, this affinity is the result of the assemblage of a heterogeneous web of actors, power, practices and discourses. Its political (and unstable) character requires a permanent work of legitimation. Embedded in a neoliberal food regime, technologies are increasingly constructed as mere procedures and devices. Articulated as beneficial for all producers and consumers, their social, economic and political undercurrents are obscured [52]. In this context, determinist views of technologies bolster to the extent that sustainability is expected to stem directly from technological innovation.

Discussions on current technological-led responses to environmental issues should not only address how the latter are shaped and defined as an urgent need. The understanding of smart agricultural technologies must also consider that they are one more component within the broader logics of capital accumulation, which also include the expansion of commodity markets, flex cropping, financialization, land grabbing, dispossession, enclosures, as well as social, economic and productive exclusion. In sum, analyzing technological changes should account for its different drivers and consequences, as well as how these changes are put forth by the need of extended accumulation.

Conflict of interest statement

Nothing declared.

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