Society and Natural Resources, 14:555–570, 2001

0894-1920/2001 $12.00 + .00

Industrial Dynamics and the Problem of Nature

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Existing literature suggests that food, fiber, and raw material sectors differ from manufacturing in significant ways. However, there is no analytical basis for engaging the particular challenges of nature-centered production, and thus the distinct ways that industrialization proceeds in extractive and cultivation-based industries. This article presents a framework for analyzing the difference that nature makes in these industries. Nature is seen as a set of obstacles, opportunities, and surprises that firms confront in their attempts to subordinate biophysical properties and processes to industrial production. Drawing an analogy from Marxian labor theory, we contrast the formal *and* real subsumption of nature *to highlight the distinct ways in which biological systems—in marked contrast to extractive sectors—are industrialized and may be made to operate as productive forces in and of themselves. These concepts differentiate analytically between biologically based and nonbiologically based industries, building on theoretical and historical distinctions between extraction and cultivation.*

Keywords agricultural biotechnology, agriculture, industrialization, natural resource industries, resource extraction

Postindustrial prospects to the contrary, primary product industries remain of tremendous importance to the world economy. Not only do they supply critical inputs to

Received 1 July 1999; accepted 4 October 2000.

We thank members of Michael Watts's graduate reading group, Fred Buttel, Michael Goldman, Andrew Pickering, and three anonymous *SNR* reviewers for very helpful feedback on earlier versions of this article.

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industrial production, but they also represent major circuits of capital accumulation for some of the world's largest corporations. As such, nature-based industries continue to shape patterns of regional development—for example, class and economic structures, resource use and ownership, human settlement and migration patterns, community power structures, and even local cultures—the world over. Although recent technological advances have reduced the raw material intensity of many industrial production processes (Socolow et al. 1994), the growth of the world economy continues to be associated with rising absolute quantities of raw material consumption, including the appropriation of new raw materials for industrial processes (Bunker 1996). Even under late capitalism, the mobilization of raw materials and energy remains a crucial basis for the reproduction of industrial societies.

Aside from being of immense practical importance, food, fiber, and raw material industries pose interesting theoretical challenges regarding the relationship between society and the natural environment. Attendant with the increasing scale and pace of global environmental change, recent decades have seen a proliferation of attempts by social theorists of various persuasions to "bring nature back in" to their analytical frameworks (for reviews, see Braun and Castree 1998; Goldman and Schurman 2000). In this article, we seek to build on this tradition in a way that focuses on nature-based industries as a locus of the society–nature interface, with an emphasis on understanding how these industries differ systematically from manufacturing sectors. Drawing on a number of key influences (Mann and Dickinson 1978; Bunker 1985, 1989; Goodman et al. 1987; Mann 1990; Barham et al. 1994), we contend that the physical properties of natural resources, the time required for biogeophysical (re)production processes to occur, and the fact that natural resources are extensive in space, found in particular locations, and vary in quality, all affect the capital accumulation process in unique and important ways. In short, informed by various debates within social theory concerning the problem of nature, our objective here is to explore how nature matters to the dynamics of industrialization.

The goal of this article, then, is to develop an analytical framework that takes the "problem of nature" seriously, both for capital and for social theory. The framework explores how the intimate relationship with nature in food, fiber, and raw materials industries poses a unique set of obstacles, opportunities, and surprises to firms as they seek to subordinate biophysical properties and processes to the dictates of industrial production. These obstacles, opportunities, and surprises take a variety of forms, and derive from capital's inability to fully reproduce nature (O'Connor 1988), and to predict and control nature more generally.[1] Within this framework, the defining feature of nature-based industries is that they *confront nature directly* in the process of commodity production. Firms operating within these industries are thus forced to grapple with the unexpected events, challenges of industrialization, and profit-making opportunities that emerge from their interactions with the biophysical world. This definition is intentionally broad, and includes industries based on raw materials extraction as well as those based on plant and animal cultivation. Indeed, as we argue later, extraction and cultivation represent the two fundamental logics of production operating within nature-based industries, and, as such, have important implications for industrial organization. At the same time, these general distinctions do not fully account for the substantial differences among nature-based industries. Indeed, a nuanced understanding of the problem of nature in its varied and variable manifestations requires that nature-based industries be analyzed on their own terms and in specific historical and regional contexts. What we offer is a point of departure for commencing this project.

To that end, we introduce the concepts of the *formal* and *real subsumption of nature*. Under the *formal subsumption of nature*, firms confront nature as an exogenous set of material properties and bio-/geophysical processes, but are unable to directly augment natural processes and use them as strategies for increasing productivity. In contrast, under the *real subsumption of nature*, limited to biologically based industries, firms are able to take hold of and transform natural production, and use this as a source of productivity increase. In adapting these concepts from Marx's notions of the formal and real subsumption of labor, our intention is to highlight some of the different ways in which biophysical systems are industrialized and, in some cases, can actually be made to operate as productive forces in and of themselves. Taken together, the distinction between the formal and real subsumption of nature makes it possible to differentiate analytically between nonbiologically based and biologically based industries while maintaining a distinction between extraction and cultivation that is both theoretical and historicized.

In what follows, we first review some previous attempts to explore "nature's difference" as it affects the industrialization of nature-based industries. These attempts provide an important foundation for considering the ways in which natural production processes shape firm strategies and industry structure. Yet within the existing literature, there has been a tendency to see nature as a set of relatively rigid constraints or obstacles facing capital. While this is an important insight, it ignores the ways that such obstacles can also open up new opportunities for accumulation and gives insufficient weight to the role of nature as a source of variability and surprise. More generally, the literature fails to provide a unifying framework for looking at nature-based industries. In contrast, we seek to develop a framework that can encompass both extraction and cultivation.

Political Economy and the Problem of Nature

At the most general level, how does one account for the "difference" that nature makes to the political economy of nature-based industries? On one side lies the danger of overlooking the significance of the biophysical world in nature-based industries and lapsing into pure social constructionism. On the other lies the specter of environmental determinism.

One important perspective on the society–nature interface comes from the "social production of nature" school, which emphasizes the historically constituted character of nature, and ideas of nature (see Schmidt 1971; Williams 1980; Smith 1984). Strongly influenced by Marx's debate with Malthus, the social production school inherits a "constructivism" from Marx that sees the notion of natural limits and natural resources as culturally and technologically informed *appraisals* of nature, rather than windows on nature itself (see especially Harvey 1974). While important, the social production school tends to minimize the influence of nature as a material force. As Benton (1989, 64) argues about Marx, "Marx underrepresents the significance of non-manipulable natural conditions of labour processes and over-represents the role of human intentional transformative powers vis-à-vis nature." Similarly, Castree (1995, 13) points to the importance of "both the ontological reality of those entities we term 'natural,' and the active role those entities play in making history and geography." While the social constructivists are right to argue that nature should not (indeed cannot) be de-historicized (i.e., placed in a category outside of human history, politics, and social relations), we agree with those who argue that there *is* a material "other" to natural processes that shapes the interaction of the natural and social worlds (Freudenburg et al. 1995, Pickering 1996; Demeritt 1998) and that poses a unique set of challenges for industrialization (Bunker 1989).

More than a decade ago, Stephen Bunker advanced a number of claims about the difference that this materiality makes in extractive industries. Bunker's key contribution was the idea that extractive industries are far less subject to human control than are "transformative activities" (i.e., manufacturing industries). Specifically, Bunker noted that extractive industries were "inexorably constrained by geological, hydrological, and biological forces" (1989, 592), and that "time and space work differently in extraction and agriculture than they do in industrial production" (p. 590). Simply put,

> If production is the incorporation of energy into matter, then industrial production starts and ends at the same time as the labor that defines it. In agriculture, much of the production occurs after labor has modified the conditions of that production and before labor harvests that product, while in extraction, actual production is anterior to human labor, and in the case of minerals occurs within much longer time frames than humans normally use. (Bunker 1989, 591)

In addition to identifying these important differences between transformative and extractive industries, Bunker was among the first to take the question of nature seriously enough to ask how it matters to industrial organization, geographically and historically.

Building on these ideas, Barham et al. (1994) have developed a general framework that identifies two sets of forces as key shapers of extractive industries. The first is the *context of global capitalism*, or the key power hierarchies that structure the relationships among core and peripheral states and firms, as well as these states' and firms' strategic behavior. The second is the *specific features of the raw materials themselves*—their physical characteristics, underlying scarcity, variations in grade or quality, location in space, technology of extraction and refining, and eventual use (p. 6). Individually and together, these characteristics are hypothesized to affect industry structure, market power, states' and firms' ability to act strategically to capture resource rents, and the distribution of economic benefits from extraction.

One of the strengths of the Barham et al. framework and these authors' efforts to apply it is that it relates specific resource characteristics—not least spatial distribution—to the organization of particular industries (see, e.g., Barham 1994). Another is the model's sensitivity to the dynamic influences on market structures that can affect industrial development (see Bunker and Ciccantell 1994). However, this approach is also characterized by important shortcomings. Specifically, because industries that rely on cultivation are excluded, the authors are unable to provide a comprehensive theorization of the "problem of nature" and to identify the different ways in which nature matters to extractive industries versus those based on cultivation. Barham et al. also conflate the physical properties of a resource with social issues, leading them to confuse what is and is not unique to nature-based industries. For example, the fact that demand and the availability of substitutes (both of which are in large part socially determined) shape the organization and operation of raw materials industries does not distinguish them qualitatively from manufacturing activities (see especially Barham et al. 1989, 18–20).[2] What does set them apart is that because they confront nature directly, they utilize materials and confront processes over which capital has only limited control.

Ted Benton (1989) takes an alternative approach to the uniqueness of nature-based production, arguing that it is characterized by a different labor process than that characterizing handicraft and manufacturing activities. Agricultural (and other similar) labor processes, he claims, are "eco-regulatory," aiming to sustain or regulate rather than transform the subjects of their labor (i.e., raw materials, the natural environment). Benton identifies four central features of eco-regulatory practices: (1) labor is applied to optimizing conditions of transformation, that is, organic processes, which are relatively impervious to intentional modification; (2) labor is primarily aimed at sustaining, regulating, and reproducing, rather than transforming, those conditions and processes; (3) the organic character of production shapes the temporal and spatial distribution of social production; and (4) certain natural conditions of production (e.g., water, sunlight) act as both conditions of production and the subjects of labor.

There are clearly important parallels between Benton's and Bunker's juxtaposition of nature-based versus productive or transformative activities. Yet there are also significant differences. Where Bunker's theorization draws heavily on his observation of extractive sectors such as mining, Benton's derives largely from a focus on agriculture. But even Benton, who brings the importance of organic processes to the fore, persists in emphasizing the relative imperviousness of these processes to human manipulation, thereby downplaying the importance of contemporary efforts to industrialize natural processes within agriculture.

In contrast, certain theorists within the tradition of agrarian political economy have sought to develop a model of the industrialization of agriculture. Considerable emphasis has been directed at the distinctive ways in which the "obstacles" or "structural constraints" posed by agriculture's biophysical basis shape and constrain industrialization and the strategies of industrial firms. The widely cited Mann–Dickinson thesis (1978; see also Mann 1990), for example, holds that because agriculture is subject to natural production processes (particularly biological time in plant and animal growth), the adoption of wage labor is impeded and retarded. Other "natural obstacles" to capitalist development in agriculture include the perishability of crops and other marketing restraints and the land-based character of production (Mann 1990). Firms attempting to subordinate agricultural production to industrial operations must minimize or bypass these natural obstacles. In general, this line of argument privileges the question of labor deployment, wherein the presence or absence of wage labor serves as a litmus test for the degree of capitalist penetration in agriculture. Although insightful, this relatively narrow focus neglects the question of how biophysical characteristics shape the organization and development of agro-industry more broadly.

Working within the same tradition, Goodman et al. (1987, 1–2) identify three major structural constraints facing the industrialization of agriculture. These include nature as the biological conversion of energy; nature as biological time in plant growth and animal gestation; and nature as space in land-based rural activities. According to Goodman et al., industrial capitals employ two main strategies to overcome such constraints. *Appropriationism* refers to the efforts of firms to transform discrete aspects of agricultural production into industrial activities, the products of which are then reincorporated back into agriculture as industrial inputs. One example is fertilizer, which was initially produced on the farm as recycled organic waste, but was eventually replaced by synthetic nitrogen, developed and manufactured by chemical companies and sold to farmers as a commodity input (pp. 31–32). *Substitutionism*, on the other hand, refers to ongoing efforts to develop industrial substitutes for agricultural products, bypassing altogether particular natural constraints (p. 2). The mass production of margarine to replace butter is a prime example.

The Goodman et al. framework has made a major contribution to understanding the ways in which biophysical properties and processes shape patterns of agricultural industrialization. The twin concepts of appropriationism and substitutionism, however, do not offer an adequate basis for analyzing the ways in which biological productivity can be harnessed directly as a force of production. Moreover, not unlike Mann and Dickinson (1978), and Mann (1990), Goodman et al. mainly view nature as a set of structural constraints, obstacles, or conditioning factors shaping agro-industrialization, rather than as a source of opportunity and surprise.

In this respect, Jack Kloppenburg's (1988) analysis of plant biotechnology and the progressive commodification of the seed provides a more useful illustration of how one might conceptualize the industrialization of biological processes, and how natural characteristics (and obstacles) can actually become integral to the dynamics of accumulation within sectors. Kloppenburg specifies how a biological system can be transformed into a "vehicle for accumulation," a process in which capital actively intervenes in and circulates through nature (p. 8). He emphasizes the biological barriers facing capital in its attempts to penetrate plant breeding, yet goes on to show how public science, agricultural research, and law were mobilized to progressively commodify the seed. In the process, he explains how the "biological lock" of hybridization operates as an accumulation strategy, arguing that hybrids have allowed agribusiness firms to effectively control the biological reproduction of crops as a form of capital.

This approach is highly suggestive for thinking about the ways that biological productivity can be augmented by industrial interventions, thereby becoming an essential dimension of firm strategies and industrialization. Kloppenburg, however, falls short of specifying how the seed and biological systems more generally are actually subsumed under the logic of capital and made to act as a force of production. Moreover, though a tremendously important contribution to the historical political economy of agriculture, Kloppenburg's approach is not developed as a general framework for analyzing nature-based sectors per se.

In sum, what is not emphasized in these literatures (Kloppenburg notwithstanding) is the way that natural obstacles can also become opportunities for competitive advantage based on strategic and competitive mobilization around such obstacles, as well as on attempts to overcome them. In addition, emphasis on relatively static obstacles ignores the dynamic aspects of natural systems, which render them variable and unpredictable, and hence capable of surprise. This capacity for surprise is an important aspect of the "difference" of nature-based industries, particularly in industries such as agriculture, forestry, and fisheries, where the emergent and unpredictable character of biological systems represent significant challenges for capital. Any adequate theory of how industrial firms attempt to subsume the "problem of nature" thus needs to account for all three of these dimensions—obstacle, opportunity, and surprise.

Nature as Obstacle, Opportunity, and Surprise

Any effort to analyze nature-based industries must be careful to incorporate a view of the problem of nature that does not dissolve into simple binary oppositions of "nature" and "capital," or "industry" and "environment." Like others, we realize the difficulties of overcoming such dualisms and do not claim to have developed a new vocabulary that successfully moves beyond them (see, e.g., Schmidt 1971; Cronon 1983; FitzSimmons 1989; FitzSimmons and Goodman 1998). Yet categories such as "first" and "second" nature, while highlighting the progressive melding of natural and social histories, do not do justice to the varying degrees to which nature is produced and reproduced within the circuits of capital accumulation, nor paradoxically to the enduring importance of nature per se even when "colonized" or "civilized" (see Castree and Braun 1998). As noted earlier, existing analyses of nature-based industries, while recognizing the analytical importance of the biophysical world, have often employed such binary logic by viewing nature as either a set of structural obstacles or a set of contingencies that remains outside of the endogenous logic of capital. "Nature" is thus understood primarily as a feature of the firm's external environment rather than as part and parcel of the basic problem of organizing and implementing production.

Such accounts are accurate as far as they go—that is, the biophysical world does indeed present all sorts of obstacles to accumulation, and the development of nature-based industries is very much a product of the efforts of firms to overcome such obstacles. Yet, an overemphasis on constraints tends to downplay the ways in which one firm's obstacle may become another's competitive advantage or opportunity. In this context, firms are not only limited by natural processes and inputs, but can carve out a niche for themselves as they successfully confront and even "improve upon" these processes. Another weakness of a purely structuralist or obstacle-oriented account of nature is that it is static, and ignores the fact that bio-/geophysical processes operate according to their own rules and dynamics and are inherently unpredictable. Two examples are the emergence of new viruses and pests that threaten intensive animal and crop-based agro-industry, and the role of El Niño in altering fish migration patterns. We opt for a conceptual approach that gives nature a genuine role in shaping the industrialization process, allowing for natural variation, evolution, and surprise.

For starters, then, we make a basic distinction between nature-based industries that are biologically based and those that are nonbiologically based. Indeed, the fact that biological systems have certain characteristics that are not present in inanimate systems has profound implications for the organization of production and the general trajectories of accumulation within these sectors. In the words of biologist Ernst Mayr (1997, 20–21):

> Organisms are fundamentally different from inert matter. They are hierarchically ordered systems with many emergent properties never found in inanimate matter; and most importantly, their activities are governed by genetic programs containing historically acquired information, again, something absent in inanimate nature.

Mayr (1997) goes on to note that in contrast to inanimate systems, the distinctive properties of biological organisms give them a capacity for evolution, self-replication, growth and differentiation via a genetic program, metabolism (the binding and releasing of energy), self-regulation, response to environmental stimuli, and change at both the phenotypic and genotypic levels. Though this distinction may seem obvious, it is one that has been minimized by the social science literature.

Two crucial implications originate in this "difference." The first is that biological production (including production time) can be consciously manipulated (up to a point), whereas geological production is for all intents and purposes beyond the scope of human control. This opens the door for what we term the real subsumption of nature. Second, the particular risks, uncertainties, and surprises associated with biological systems can have profound influences on industrial organization and regional development. In fact, within these sectors, efforts to further control and subordinate biological systems to the dictates of industrial production will almost inevitably generate new risks and vulnerabilities for the production process, not to mention unforeseen externalities. Many of these risks and uncertainties will in turn open up new spheres of accumulation, as has occurred with the pesticide and animal health industries.

General Tendencies in the Industrialization of Nature

Industrialization in nature-based sectors is often portrayed as a progressive dynamic under which capital attempts to extend and deepen its control over biophysical properties and processes or bypass "natural obstacles" altogether through such strategies as appropriationism and substitutionism. The systematic application of scientific knowledge and human labor are the key vehicles for this ongoing process. Metaphors for describing this dynamic abound: commodification, rationalization, capitalization, subordination, etc. The critical question, however, is not which metaphor fits best, but rather how one might analyze the different tendencies and dynamics that are involved in the industrialization of nature in a manner that encompasses both biological and nonbiological sectors without obscuring the fundamental differences between them.

Taking this as our point of departure, we develop a framework that differs from the perspectives just discussed in two important respects. First, as elaborated earlier, we build on the view of "nature as obstacle" by emphasizing the ways in which nature also serves as a source of opportunity, uncertainty, and surprise for economic actors. Second, and more pertinent to the discussion of general tendencies, we argue that the basic processes of industrialization operating within nature-based industries (biological and nonbiological) can be analyzed more fruitfully by focusing on how biophysical properties and processes are engaged and mobilized in the production process.

To this end, we develop the concepts of the *formal* and *real* subsumption of nature. Inspired by Marx's notion of the formal and real subsumption of labor, these concepts provide tools for analyzing general tendencies in nature-based industries. For Marx, the distinction between the formal and real subsumption of labor turned on the distinction between absolute and relative surplus value. He used the concepts both as part of his theoretical argument concerning surplus value and as key coordinates for charting the historical transition to a system of wage labor where surplus value is extracted on the basis of systematic increases in labor productivity (relative surplus value—real subsumption) rather than through an extension of the working day (absolute surplus value—formal subsumption) (Marx 1967).

In adapting these concepts to analyze nature-based industries, our aim is not to devalue the place of human labor in the production process, nor to engage the complex involutions of value theory. Rather, we use these concepts as a means to highlight some of the different ways in which biophysical systems are industrialized and, in some cases, made to operate as productive forces in and of themselves. Taken together, the distinction between the formal and real subsumption of nature makes it possible to differentiate analytically between nonbiologically and biologically based industries while maintaining a distinction between the two fundamental logics of production operating within nature-based industries, namely, extraction and cultivation.

Formal Subsumption

In many nature-based industries (biological and nonbiological), natural processes and products are not subject to direct industrial transformation, but are simply exploited by firms in the process of commodity production. In such sectors, firms may invest in gaining access to or control over natural resources or ecosystems, but are unable (or unwilling) to control, intensify, manipulate, or otherwise "improve" upon nature to suit their purposes, with the result that nature is only formally subsumed by capital. Within a "logic of extraction," therefore, firms confront the biophysical world as an exogenous set of stocks or flows, biophysical processes, and material characteristics.

Unable to intentionally transform these inputs and biophysical processes, such firms must adjust their production strategies to address the exigencies of nature.

Natural schedules of biological or geophysical (re)production represent one exigency of nature to which firms in extractive sectors must adapt. Such firms commonly confront pronounced seasonal fluctuations in resource availability (e.g., seasonal salmon migration patterns), growth cycles that exceed normal investment horizons (e.g., slow-growing forest tree species), or natural production processes that operate on time scales that make the resources effectively nonrenewable (e.g., oil, coal, various minerals). This dependence on natural production schedules can pose serious challenges to the continuous deployment of labor and machinery, in space as well as time, and to the predictability of production. It may also give rise to nonwage and sometimes particularly repressive types of production relations, as firms pass the costs of discontinuous production schedules on to petty producers or workers (Mann 1990; Watts 1994; Prudham 1999).

The physical quantity of resources available is another type of obstacle facing firms working within extractive sectors such as hard rock mining, oil exploration, or old-growth logging. Since nature is (of necessity) approached as a stock of resources under formal subsumption, the amount and actual location of the resource, together with its spatial distribution, exert a significant influence on the location and character of production, as Bunker (1985; 1989) has emphasized. In nonbiologically based industries, decreasing supplies of a resource relative to demand pose a constant threat, with the potential to radically alter industrial geographies and to encourage substitutionism as price increases make it profitable for firms to search for alternative raw materials. An example is provided by the oil crisis in the early 1970s, which provoked a widespread search for alternative energy sources. It is true that in sectors such as oil, firms can and do react to scarcity by searching for and finding new sources of oil. They can also develop new ways to extract oil in situ, as witnessed in the development of advanced deep ocean drilling operations and enhanced recovery techniques using steam and gas injection. But despite these technological fixes, firms cannot increase the absolute quantity of oil at a particular location (nor in the aggregate, for that matter).[3]

Under formal subsumption, capital must also confront the challenges of in situ production, representing one aspect of the "land as space" constraint identified by Kautsky (1988) and Goodman et al. (1987). With in situ production, capital is forced to circulate around nature, and machinery must be deployed in a way that adjusts to the landscape. In such cases, the predictability and calculability of production, so central to increasing productivity under capitalist competition, are challenged. The deployment of workers and machinery outside of a factory setting may require firms to adjust to a variety of problems, ranging from difficult and variable physical conditions that are not conducive to the use of machinery (e.g., steep slopes in mountain logging) to monitoring problems in labor supervision (see Prudham 1999; Barham and Coomes 1994). Perhaps commercial fishing represents the most extreme case, where unpredictable ocean conditions, the extensive deployment of boats, and pronounced seasonal discontinuities have helped perpetuate fragmented industry structures and large numbers of "independent" fishing units (Marchak et al. 1987; Apostle and Barrett 1992).

Under formal subsumption, firms must also accommodate a wide range of physical and biological resource characteristics. While the importance of material specificities is hardly unique to nature-based industries (cf. Sayer 1995), their significance is elevated in such industries because firms must confront these characteristics directly as the legacy of an external production process. For example, the perishability of certain agricultural crops (and fish) places severe time–space constraints on commodity provisioning systems, while at the same time opening up opportunities to those firms able to develop processing techniques that preserve these foods. This dynamic has been and remains central to struggles between the fresh and canned fish sectors (see McEvoy 1986). Similarly, the incidence of most minerals in ore complexes often creates strong incentives for the development of mine-mouth processing in order to minimize transport weights, with important implications for industrial geographies. While it is difficult to offer general statements about industrial tendencies, the empirical challenge is to develop sufficient understanding of specific biophysical processes and properties in order to identify what kinds of influences they have on industrial structure and organization, in specific geographical and historical contexts.

Efforts to formally subsume nature, however, are not solely concerned with overcoming biophysical obstacles. As numerous studies of oil, diamonds, and other extractive industries have shown, competitive advantage often derives from proprietary access to particular resources. Under formal subsumption, where natural production processes are not (by definition) subject to productivity-enhancing manipulation or intensification, profitability may be enhanced simply by establishing property rights over natural resources. Hence, strategic rent seeking is often an important aspect of firm behavior and overall industry dynamics (see Barham 1994). In fact, limited availability and access can act as both obstacle (exclusion of some firms from capture, and the inability of capital to reproduce nature) and opportunity (the flow of rents to those firms that gain access) for firms. It may also stimulate the search for alternative sources or substitutes along the lines outlined earlier, as well as interventions designed to augment the quantity and quality of biological resources. In some cases involving biological resources, moreover, firms may seek to move from formal to real subsumption, replacing a logic of extraction with one aimed at enhancing biological productivity.

Real Subsumption

The key to understanding the distinction between formal and real subsumption of nature lies in the difference between biological and nonbiological systems and the unique capacity to manipulate biological productivity. The *real subsumption of nature* refers to systematic increases in or intensification of biological productivity (i.e., yield, turnover time, metabolism, photosynthetic efficiency)—a concept that obviously applies only to those biologically based sectors that operate according to a logic of cultivation. Moreover, although the concept applies to productivity increases based on the use of exogenous inputs such as growth hormones, synthetic fertilizers, pesticides and herbicides, and improved environmental control, the primary vehicle driving the real subsumption of nature is the manipulation of the genetic program, both through traditional breeding programs and, more recently, through the application of new biotechnologies, such as recombinant DNA techniques. The desired result, of course, is higher yields, shorter turnover times, improved disease resistance, etc. Nature, in short, is (re)made to work harder, faster, and better.

The parallels between the real subsumption of labor and the real subsumption of nature should be obvious. In making the analogy, however, our intention is not to devalue the place of human labor in these sorts of production systems. Nor do we employ the notion of real subsumption as a euphemism for the progressive obliteration of any meaningful distinction between the social and the natural as the production and reproduction of nature proceed apace, and as world energy and raw materials are increasingly appropriated and used to increase industrial productivity. Rather, our purpose in drawing such a parallel is to highlight the way that competitive pressures lead firms to augment productivity through the systematic intensification of biological growth. The real subsumption of nature thus represents a new and distinct avenue for productivity advance through "improving" nature directly rather than simply making labor more productive.[4]

Under real subsumption, then, capital circulates *through* nature (albeit unevenly) as opposed to around it. Biological systems are made to act as actual forces of production. This is true whether or not the value generated through real subsumption is actually "appropriated" by industrial capitals that operate in upstream or downstream sectors. Nor does it matter if the process of real subsumption is actually subordinated to a strategy of appropriationism (e.g., using proprietary genetics to lock in sales of chemicals, as in the case of Monsanto's RoundUp Ready Soybeans). Indeed, if appropriationism refers to the strategies employed by firms to carve out new spheres of capital accumulation from the agricultural production process, real subsumption refers to a more general tendency of integrating accelerated biological returns into the circuits of capital and thereby making nature act as a force of production. Issues of motivation and distribution—that is, who actually captures the benefits or bears the costs associated with these accelerated biological returns—are empirical questions that can only be understood and explained in specific cases.

By distinguishing between real subsumption and appropriationism, we do not want to suggest that Goodman and his colleagues (among others) are unaware of the ongoing tendency to accelerate biological productivity within agro-industry, particularly in the context of the new biotechnologies (for an early example, see Yoxen 1981). In fact, Goodman and Redclift (1991) have spoken of the new biotechnologies in precisely these terms (see p. 169). Our point is rather that appropriationism only gets at part of the dynamic by which nature is transformed into a productive force, and that the concept of real subsumption provides a necessary complement.

The real subsumption of nature thus represents a way of reconceptualizing biotechnology, defined broadly as "the use of living organisms to solve problems or make useful products" (Caswell et al. 1994, 1). In contrast to those who argue that the new biotechnologies represent a qualitatively different approach to the problem of nature within biologically based sectors, we see the progressive development and application of these new biotechnologies as a new round in the ongoing expansion and intensification of both real subsumption and appropriationism. Clearly, the capacity for transcending the species barrier afforded by the new biotechnologies represents a massive expansion of capital's ability to subordinate biological processes to the dictates of industrial production. At the same time, however, it also represents an extension of a general tendency to manipulate the genetic program of particular organisms. As Kloppenburg (1988) points out, with the development of hybridization, the control of plant reproduction had already emerged as an accumulation strategy, with the seed itself serving as the "nexus" in the accumulation cycle. The new biotechnologies greatly extend the reach of such strategies, as capital literally takes hold of and circulates through biological systems—"outdoing evolution," in Kloppenburg's words.

A concrete illustration of the contrast between formal and real subsumption of nature is provided by the worldwide transition from extraction to cultivation in the forest industry (Sedjo and Lyon 1990; Marchak 1995). Depending on regional context, this transition is in various stages, involving extensive efforts by firms and state agencies to intervene in the biological basis of forest growth through the development of intensive cultivation systems. This project involves multiple fronts of real subsumption, including the use of chemical fertilizers and pesticides, intensive nursery operations for seedling cultivation, and hand and mechanical planting of forest trees. It also includes attempts to directly manipulate genetic material, both through tree improvement (Daniels 1984) and, more recently, through genetic engineering (Haines 1994). The contrast between extractive forestry, based on the formal subsumption of nature, and intensive plantation forestry, based on the real subsumption of nature, highlights the potential for harnessing biological growth as a source of increased productivity, with capital circulating through rather than around nature. Instead of confronting trees as "ready-made" objects, the logic of plantation forestry involves ongoing intervention in and alteration of tree growth processes. Moreover, although silvicultural techniques for augmenting forest growth have centuries of scientific and practical development behind them, the rapid depletion of old-growth forests suggests that forest intensification will continue to become an ever more important dimension of regional industrial development processes in places as far flung as Brazil, New Zealand, the American Southeast, and the Pacific Northwest. In the process, bioindustrial strategies based on the accelerated growth of high quality wood fiber have become a crucial basis for competition, within and between such regions.

Real subsumption is thus a strategy by which firms seek to alter biophysical processes, primarily through the manipulation of the genetic program, thereby opening up new opportunities for accumulation. It is hardly surprising therefore that germplasm has emerged as *the* strategic resource in biologically based industries. Today, the self-replicating capacity of the genetic program combined with the awesome power of the new biotechnologies promises to reshape entire sectors, ushering in a new phase in the real subsumption of nature. Yet it is important to emphasize that even though the genetic program may be the material terrain of competition and innovation, it is in the legal sphere that the contours of this emerging landscape of competition and profitability are being determined—a fact that will generate increasing conflict over intellectual property rights over "novel life forms" and the corresponding distribution of risks and benefits associated with the accelerating industrialization of biological systems.

Finally, it is important to note that efforts aimed at intensifying the real subsumption of biological systems will inevitably be confronted with further surprises and uncertainties. The production of commodities from nature, whether via the formal or real subsumption of natural processes, will always be selective or partial. Because of the incomplete character of ecological information embedded in prices, emphasis on maximum short-term returns in capitalist economies, and the selective biases of economic valuation, industrial production tends to degrade the environment, both in terms of the depletion of specific raw materials and in terms of nature as "conditions of production" more broadly (O'Connor 1988; O'Connor 1998; Altvater 1993; Harvey 1996). Moreover, these tendencies are the subject of intense political struggle over who should pay for maintaining natural systems and bear the costs of their degradation, often with significant implications for the organization of industries and their social regulation.

Real subsumption, including the application of the new biotechnologies, hardly eliminates the production of risks and negative environmental outcomes. In agriculture, for example, real subsumption of biological growth processes may be quite compatible and even dependent on formal subsumption of other natural inputs such as ground water and soil fertility, which may in turn be depleted. Moreover, genetic engineering and the development of transgenic organisms may even create more serious and intractable risks than traditional cultivation regimes (cf. Beck 1992). Such risks are manifest in the potential escape and proliferation of novel life forms, the creation of super weeds or new virulent strains of virus and pathogenic bacteria, and the disruption of larger ecological processes (Krimsky and Wrubel 1996; Rissler and Mellon 1996). The political implications of these risks are now being witnessed on multiple fronts, most prominently in the case of genetically modified foods.

Industrial Dynamics and the Problem of Nature

Of course, every industry is ultimately "nature-based" and, as David Harvey (1996) reminds us, all processes of industrialization—and social change more generally—are fundamentally ecological (or socioecological) projects. By theorizing about a specific category of "nature-based" industries, we are not trying to obscure the dependence of all economic processes on the biophysical world. In our view, though, there is something categorically different about those industries or sectors that involve the direct transformation of biophysical properties and processes. And though it seems pointless to develop a hard and fast rule for determining what is "in" and what is "out," we contend that it is important to think systematically about some of the general tendencies manifest in sectors such as mining, forestry, fisheries, and agriculture that are unambiguously involved in the direct transformation of nature. In short, all of the firms within these "primary" sectors engage the problem of nature in more direct fashion than firms in manufacturing sectors such as textiles or automobiles, where "nature" has already been reduced to raw material inputs.

That said, this article has sought to build on and go beyond existing efforts to theorize the problem of nature in food, fiber, and raw materials industries. Our approach emphasizes the ongoing relationship and feedback effects occurring between industrial processes and systems, on the one hand, and natural processes and systems, on the other. Moreover, whereas previous efforts to theorize nature-based industries have focused either on extractive industries or on industries that rely on cultivation (i.e., agriculture), our concern has been to elaborate a framework that is broad enough to incorporate both. By developing an analogy from Marxian value theory, we have argued that the concepts of the formal and real subsumption of nature are well suited to this task. The formal subsumption of nature applies to industries that operate according to an extractive logic; in these industries, the productivity of natural processes remains unchanged and firms must accept certain constraints imposed by nature. The real subsumption of nature, in contrast, applies exclusively to industries that depend upon cultivation, and in which industrial and natural processes become integrated in the pursuit of increased productivity and profitability.

Only biologically based industries offer the possibility of shifting from formal to real subsumption. While firms operating in nonbiologically based industries are effectively "stuck" in an extractive logic, firms in biologically based industries can (and often do) attempt to substitute a logic of cultivation for a logic of extraction. This process is manifest in the fisheries sector, for example, where aquaculture is becoming increasingly common and significant, and in the forestry sector, as already noted. In some instances, moreover, both logics might be employed simultaneously within the same firm, such as forest products firms that simultaneously log old-growth forests and engage in intensive silviculture. Ultimately, of course, the mix of formal and real subsumption within an industry will reflect the ever-changing landscape of competition and profitability and the competitive strategies of individual firms.

While our use of the *formal* and *real* subsumption of nature is designed to illuminate some of the processes occurring in, and working to shape, nature-based industries, any analysis of a particular industry obviously needs to locate these processes within a broad political economy perspective. Much empirical work needs to be undertaken to unpack the actual process of social and environmental change in nature-based industries and to relate those processes to specific industries, in specific places, during specific historical periods. The contrasting tendencies of formal and real subsumption, and the broad political economy perspective laid out here, are intended to provide a framework in which this research can usefully proceed.

Notes

1. For the purposes of this article, we use *nature* to refer to the nonhuman, biogeophysical world.

2. The elasticity of demand, for example, is just as relevant to manufacturing as it is to raw materials industries. The same is true of the features of productive (or extractive) technologies: Product-specific sunk costs are just as important to auto makers as they are to agro-industry.

3. We are quite aware of the difference between the physical amount of a resource and the economically available quantity, often represented in terms of the difference between resources and reserves. We are not denying that the amount of economically available oil (or any resource) can be changed by technological and market conditions. This has nothing to do with physical stocks, nor does it pertain to the productivity of nature, but rather to the productivity of capital and labor; this is the crucial distinction between formal and real subsumption. We thank an anonymous reviewer for pushing us to elaborate these points.

4. It is also true that firms can—and indeed constantly seek to—increase productivity under the formal subsumption of nature. The difference is that within real subsumption, productivity increases are achieved by actually altering biological and ecosystemic processes, not by extracting resources more efficiently.

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