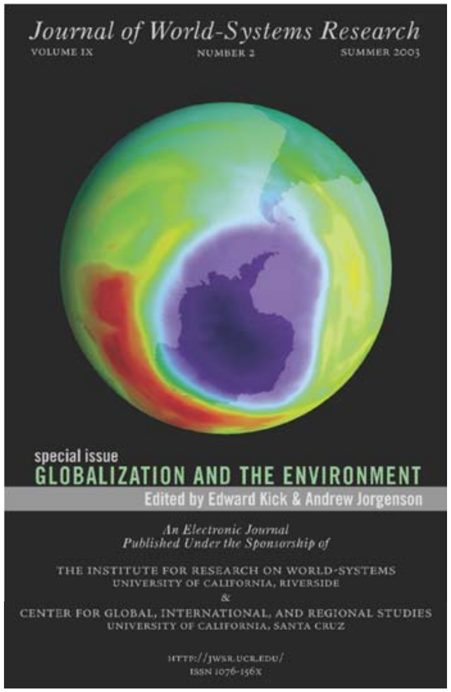

ABSTRACT

Many authors have attempted to incorporate the local into the global. World-systems analysis, though, is rooted in processes of production, and all production remains profoundly local. Understanding the expansion and intensification of the social and material relations of capitalism that have created and sustain the dynamic growth of the world-system from the local to the global requires analysis of material processes of natural and social production in space as differentiated by topography, hydrology, climate, and absolute distance between places. In this article, I consider some of the spatio-material configurations that have structured local effects on global formations within a single region, the Amazon Basin. I first detail and criticize the tendency in world system and globalization analysis, and in the modern social sciences generally, to use spatial metaphors without examining how space affects the material processes around which social actors organize economy and polity. I next examine the work of some earlier social scientists who analyzed specific materio-spatial configurations as these structured human social, economic, and political activities and organization, searching for possible theoretical or methodological tools for building from local to global analysis. I then review some recent analyses of spatio-material determinants of social and economic organization in the Amazon Basin. Finally, I show that the 400-year-long sequence of extractive economies in the Amazon reflected the changing demands of expanded industrial production in the core, and how such processes can best be understood by focusing our analysis on spatio-material configurations of local extraction, transport, and production. The Amazon is but one of the specific environments that have supplied raw materials to changing global markets, but close consideration of how its material and spatial attributes shaped the global economy provides insights into the ways other local systems affect the world-system.

Matter, Space, Energy, and Political Economy: The Amazon in the World-System

Stephen G. Bunker

INTRODUCTION

Incorporating the local into the global in analytically compatible ways poses a major challenge for scholars of both world-systems and globalization (Chase-Dunn, 2000, Tomich, 2001, Robinson, 2001). Most of these authors have attempted to incorporate the local into the global. World-systems analysis, though, is rooted in processes of production, and all production remains profoundly local. Instead of searching for the local in the global, I propose to examine the ways that the local—and particularly as manifest in the materio-spatial features of production—structures and organizes the world-system. Understanding the expansion and intensification of the social and material relations of capitalism that have created and sustain the dynamic growth of the world-system requires analysis of material processes of natural and social production in space. Examining the effects of the local on the global requires that we consider space as materially differentiated by topography, hydrology, climate, and absolute distance between places. In this article, I suggest some steps toward this goal by considering materio-spatial configurations that have structured local effects on global formations within a single, topographically, hydrologically, and geologically distinct, region, the Amazon Basin.

I first detail the tendency in world systems and globalization analysis, and in the modern social sciences generally, to use spatial metaphors to bound or contextualize social processes without considering the effects of space as it impinges on the material processes around which social actors organize economy and

Stephen G. Bunker
Department of Sociology
University of Wisconsin-Madison
8122A Social Science
1180 Observatory Drive
Madison WI 53706
bunker@ssc.wisc.edu
http://www.ssc.wisc.edu/soc/

JOURNAL OF WORLD-SYSTEMS RESEARCH, IX, 2, SUMMER 2003, 219–258
Special Issue: Globalization and the Environment
http://jwsr.ucr.edu/
ISSN 1076–156X

polity. I then examine the work of some earlier social scientists who analyzed specific materio-spatial configurations as these structured human social, economic, and political activities and organization. I consider the theoretical and methodological tools these scholars provide for the task of building analysis from local detail into global system.

I next review some recent analyses of materio-spatial effects on social and economic organization in the Amazon Basin, the largest, most complex tropical rain forest in the world and—historically and currently—a significant source of raw materials critical for world industry. Finally, I show how some of the lessons provided by the local configurations of space and matter in the Amazon have informed my colleagues' and my efforts to discover and explain mechanisms that drive the secular material intensification and spatial expansion of the world-system.

I conclude by considering materio-spatial effects of social-environmental interactions that have driven and been driven by expanded reproduction of capital. Industrial production has accelerated consumption of raw materials and thus increased the absolute space across which ever larger volumes and more numerous types of matter are transported. I demonstrate that globalization—identified as a recent or novel phenomenon by Sklair (2000) and others—is in fact the latest phase of materio-spatial expansion and intensification that emerges from technical innovations. States, firms, and sectors collaborate technically, financially, and politically to develop and implement these technologies, and this collaboration generates episodic incidents of dramatic increases in economies of scale, in industrial production, in raw material extraction, and in transport.

Technological and organizational economies of scale drive the expanded reproduction of capital; the increased absolute space across which the increasing volumes of matter consumed must be transported raises unit costs. The contradiction between economies of scale and the cost of space creates a tension out of which cost-reducing, scale-dependent innovation and organization of transport emerge. I attempt to show that these processes: (1) drive the spatial expansion of raw materials markets, and thereby (2) stimulate development of progressively cheaper, faster technologies and more extensive infrastructure for their transport, and thus, (3) drive the globalization of the world economy. I will argue that globalization can best be understood by focusing our analysis on the secular expansion and intensification of materio-spatial configurations of local extraction, transport, and production.[1]

1. Even transport, the movement of matter through space, is at each moment as local as the location of the vehicle and of the capital sunk in the built environment at each point in the space traversed.

SPACE AND NATURE IN MODERN SOCIAL SCIENTIFIC ANALYSIS

World-systems analysts use spatial terms—core, periphery, world, global—as a conceptually central organizing metaphor, but they seldom elaborate the most fundamental mechanisms and processes that expand and intensify the social and material relations of capitalism to the entire globe. This oversight is peculiar, given the strong explanations in economic theories, Marxian and classical, of mechanisms that favor agglomeration or spatial concentration of industial production. The primary reason for progressive spatial dispersion of production is that the expanded reproduction of capital creates the need for greater volumes of a greater variety of raw materials. Varied topographic, hydrological, geological, and atmospheric conditions are needed to produce all of these different types of matter.

All of this matter is naturally produced in distinct local places. Space is simultaneously a means and a condition of its production and an obstacle or cost for its transport. The vast array of raw materials consumed in expanding industrial production is therefore dispersed among multiple ecologically different locations. Industrial economies expand materially while agglomerating spatially. Accelerated depletion of the most proximate sources of each type of raw material enhances the need for seeking sources across expanded space created by increased consumption. Expanding industrial economies must therefore procure raw materials across ever greater spaces and distances. Increasing costs of distance generate incentives for states, firms, and finance to develop more efficient means—technological and infrastructural—of transport. The successive campaigns and strategies of nations striving to dominate world trade—the Portuguese, the Dutch, the British, the United States, and the Japanese—have each superceded the then-established capacities to procure and transport cheaply over great distance the raw materials they used in greatest volume. The cumulative effects of these technological and infrastructural increases have progressively globablized the world economy.

Technological and social organizational innovations to reduce the inputs needed per unit of production and to reduce the unit costs of transport[2] thus reiterate (cf. Haydu, 1998) and surpass (cf. Arrighi, 1994) the sequentially cumulative power and scale of earlier solutions to the contradiction between scale and space. Each solution depends on expanded technical economies of scale. Each scale increase accelerates the depletion of proximate sources of raw material and drives the procurement of new sources at greater distance. Each such episode

2. Unit costs of transport can be calculated by ton/mile, that is weight/distance.

thus perpetuates and exacerbates the cycle of contradiction between economies of scale and the cost of space.

The contradiction between scale and space is constant, but each solution to it is rooted in the the intersection of (1) the geography, demography, political and financial organization of the economically expanding nation and (2) the technological innovations that drive its economic growth with (3) the materio-spatial characteristics of the raw materials that these new technologies require. The reiterated solutions to this contradiction can only succeed in each instance if they take topographic, spatial, and material properties of local production into account.

The scale of the contradiction increases with each systemic cycle of accumulation (cf. Arrighi, 1994). Each solution therefore tends to be scale dependent (Bunker and Ciccantell, 2001). The reiterated solutions are thus sequentially cumulative; that is, each separate solution is distinct in the characteristics of its technological innovation and the sources of its raw materials; but the scale of its technology and the distance to its raw materials accumulate sequentially. The reiterated, cumulatively sequential, but materio-spatially distinct, solutions to the contradiction between scale and space constitute a central mechanism behind the expansion and intensification of the world system. In other words, the local—in all of its natural diversity—significantly drives the global towards its apparent social homogeneity.

Analysts of the world-system and of globalization have overlooked the contradiction between scale and space and have thus ignored its dynamic consequences. In this they follow more general trends in the social sciences. Over the past half century, social scientists have tended to consider space as the passive context, container, or boundary of social organization and activity. Space conceived thus is neither analyzed nor theorized.

To the extent that modern geographers attempt to analyze or theorize space, they tend to emphasize the social construction of space. Neil Smith (1984) for example, incorporates Schmidt's notions of second nature into Harvey's (1983) discussions of the built environment to declare that the dynamic of capital leads to a social reconstruction of nature, including of space. He interprets Marx's statement, that time annihilates space, within a generalized vision that capital recreates nature and time. Smith's subsequent critique of renewed attention to the early Marxist writings of Wittfogel betrays the extent to which geography's unhappy battle against the excesses of environmental determinism and geopolitical analysis continues to constrain radical geographers' attention to the natural characteristics and effects of space on society. Lefevbre's (1991) and Soja's (1985, 1989) oversocialized views of space manifest a similarly dogmatic rejection of any consideration of what Smith calls absolute, or natural, space. Even though David

Harvey (1983) has to address the material characteristics of space when he elaborates Marx's theories of differential rent, his explanations for the incorporation of new space into economic expansion rest completely on notions of the overaccumulation and site-specific devaluation of capital, thus ignoring the lessons about material and space in both Marx and von Thunen.

MATERIO-SPATIAL CONFIGURATIONS IN EARLIER SOCIAL SCIENTIFIC THOUGHT

Earlier social scientific traditions took the material effects of space on economy far more seriously. Wittfogel ([1929]1985) was not alone in his attention to the materio-spatial logic of hydrology and topography. In the first half of the last century, descriptive economic historians such as Richard Albion (1926) or Harold Innis (1956) analyzed specific local extractive economies by (1) the material attributes of topography, geology, hydrology, and climate that produced the resource extracted, and (2) the topographic and hydrological characteristics of the space between the locus of extraction and the locus of consumption as these characteristics affected the technology and the cost of transport across this distance. Innis and Albion both used materio-spatial analyses in ways that contributed to explanations of how and why efforts of dominant groups in Europe structured the conquest, settlement, exploitation, and struggles over the territories incorporated into European imperialist systems.

For Albion, both shipbuilding and metallurgy in Britain were constrained by the location, accessibility, and transport cost of timber.[3] The course of navigable rivers and the location of soils and climates conducive to the growth of different tree species determined the location and organization of these economically and politically critical industries. As growing demand for iron and for ships overshot the domestic supply of oak for charcoal and for timbers, these same considerations influenced the imperial strategies of a British state enormously sensitive to Admiralty needs for ships and cannon.

Albion showed that the material features—masts, keel, hull planks, rudder, or caulk and tar—of different kinds of ship required the strengths, flexibilities, shapes, saps, and sizes particular to various species of tree that grew in specific climates, soils, and elevations. Albion used these materio-spatial details to explain the geography of British imperial expansion and trade relations, as well as the organization and relations of labor, transport, and exchange in the zones thus incorporated into Britain's raw material periphery.

3. Albion notes, for instance, that the cost of animal traction limited the harvest of trees to an area of three miles or less distance from river's edge.

Similarly, for Innis, the incorporation of Canadian space into the world economy conformed to the material needs of British, French, and Spanish struggles for economic expansion and military power. The natural processes that transformed matter and energy in distinctive—topographically, hydrologically, geologically,and climatologically structured—spaces into fish, beaver, different kinds of trees, and different metals and fuels, together with the ways that river systems and land forms interacting with transport technologies created the cost of their export, molded Canada's social, economic, financial, political, and demographic organization.

For Innis, space as a differentiated condition of natural production—combined with space as an obstacle to exchange or export—determined the material composition and the location of different extractive economies. Naturally occurring spatial and material features set the parameters within which socially constructed technologies, markets, and geo-political forces determined the organization of labor, the settlement patterns and demographic characteristics of different populations, the composition of capital, the infrastructure capital was invested in, and the organization and structure of the Canadian state. The natural course, flow, and size of navigable rivers presented obstacles and opportunities to extract and export staples to world markets. Social organization and technological innovation created and adapted various means—vehicles and infrastructure—of transport. These mediated between space as a natural obstacle to access and exchange and rivers as an avenue of cheap access and export.

Space, and the topographic characteristics that determined the type and abundance of material production in that space, set the parameters for transport systems. These systems in turn determined the utility of the resources available and the cost of their extraction and export. They thus determined not only the structure, cost, and profitability of each separate extractive export economy, but also national social and political structure. State's and society's obligations to pay for these systems affected financial, economic, and political organization of the Canadian nation in enduring ways.

Like Albion, Innis related materio-spatial features of both the European core and the North American periphery to the patterns of settlement and exploitation of the newly incorporated areas. Britain lacked France's access to cheap salt, and so was obliged to settle and defend land-spaces to dry cod caught on the Grand Banks while her rival could salt the fish without landing. This disadvantage in fishing later gave Britain an advantage in moving across the Pre-Cambrian shield surrounding the St. Lawrence. The British first used this river for access to the Artic zones. There, cold temperatures and thin human populations created the best environments for the fine thick furs favored for elegant comfort in European winters. Trade routes, transport and ware-housing infrastructure, military posts, and settlements developed to support the high-value, luxury commerce of beaver pelts, particularly around the make-bulk and break-bulk affluences of tributary rivers into the larger stream. These later facilitated the influx of capital and labor for extraction of the timber required by the expanding military and commercial transport fleet in Britain.

The initial advantage that the British acquired in the control of the St. Lawrence river meant that the Hudson Bay Company paid relatively higher prices for beaver than the French could afford. When a French company penetrated Hudson Bay and established that route to Europe as a shorter distance accessible to larger ships than the St. Lawrence provided, the British were able to coopt the French agents into the Company's supply networks and thus control this more economical route to markets. The shorter trip and larger ships significantly reduced the cost of raw materials in England. The accumulating materio-spatial advantages contributed to Britain's eventual expulsion of the French from Canada. The shift to Hudson Bay favored the British economy, but led to significant economic stagnation of the established commercial centers along the St. Lawrence until the national state—under pressure from the wheat farmers initially brought in by the cheap fares, open lands, and seasonal wages made available by the lumber trade—supported the construction of canals and locks to improve, and rail lines to supplement, the river's natural channels.

Innis's comparative analysis of beaver, fish, timber, and wheat showed how the physical features of the natural resource, the topography of its natural location, and the character of its end uses and markets affected settlement and commercial patterns as well as social, economic, and political organization. These same factors determined the ratio of value to volume of the raw material exported, and thus the distribution of costs and profits along the localized nodes of its trade. The physical features of the raw material and of its sources in nature also determined the intensity and organization of labor, its demographic characteristics and location, and the costs and requirements of its reproduction. Combined, these factors determined the ratio of the volume of inbound provisions to outbound products. The beaver pelts sent down river and on to Europe, for example, occupied far less cargo space than the goods and provisions sent from Europe in trade. Logs and wheat both reversed this proportion of inbound to outbound cargo. This ratio of imports to exports determined the relative cost of freight or of passage on the inbound and outbound trip. Extra cargo space on a boat from Europe provisioning the beaver trade from Europe was very costly; passage on a timber boat returning relatively empty to Canada was far cheaper. These relative costs directly affected the cost and thus the rate of immigration, and thence settlement patterns and the cost and availability of labor. These in turn determined the cost of imported relative to locally produced goods, and thus the chances of establishing local productive economies.

The scale, type, and cost of transport technology responded to the material characteristics of the goods transported and to the size and topography of the rivers transited. City location reflected the logic of make-bulk and break-bulk locations determined by the volume of matter and the relative size and navigabililty of rivers and by the dendritic patterns formed as tributary rivers joined to form larger waterways.

Innis's theorization of matter and space did not preempt, but rather facilitated and extended, his analysis of social and economic processes. By integrating social and natural mechanisms, he could account for such temporally and spatially consequential phenomena as the changing demand and size of the world economy, the political and economic dimensions of empire and colonial resistance, or the role of conflicts in the core, first between Britain, France, and Spain, and later between the United States and Europe. Incorporation of materio-spatial data enriched his analysis of the economic, financial, and political trajectory of the Canadian nation and state.

Even the most precise of the more recent studies of the material and economic effects of space lack this close-grained analysis of specific commodities in particular places. Mandel's (1975) discussion of how technological innovations in transport reduced the natural tariff barriers of space shows considerable sensitivity to some of the physical attributes of space. Douglas North (1958), and later O'Rourke and Williams (1999), in their specific consideration of technical change in transport and its effect on world trade, attend to space as the naturally autonomous locus of socially produced technology and infrastructure. These works, however, do not achieve explanations of the interactions between space as condition of production—and therefore determinant of the kinds of economic activity apt for profitable exploitation—and space as obstacle to exchange—and therefore determinant of the location of materially bound human activity. They thus cannot achieve the dynamic dialectic that characterized Innis's or Albion's work, and that Wittfogel found in Marx's analysis of naturally produced use values. They do, however, provide paths that can contribute to analyses that integrate locally observable dynamics into world-systemic relationships.

Studies of extractive economies in the Amazon Basin provide similar paths. Their authors confront materio-spatial constraints on economy and society too obvious to ignore. Barbara Weinstein (1983), for instance, in her study of the rubber economy, notes that the Amazon Basin as an object of analysis is spatially so enormous and topographically and biologically so complex that it overwhelms the modern tendency to ignore or deny the effects of natural space on human social and economic observation. She does not explicitly analyze the effects of space and topography on the organization of the rubber trade, but the

data she presents as the empirical bases for her explanation of the rise and fall of Amazonian prosperity allow a fairly detailed vision of these effects and a judgement of their importance.

Roberto Santos's (1968, 1980) earlier and more detailed analysis of the activities of local rubber-trading firms and of their financial, social, and commercial relations with each other, with their own labor forces, with the state, and with the international buyers and suppliers that located in Belém and Manaus provides an even richer source of empirical detail. Santos appreciates space as the biologically and hydologically determined locus and condition of natural production and of space as topographically and hydrologically determining the location and relations of social production and exchange.

In these and in other works on the Amazon, it is consistently clear that the river shaped human activities far earlier and in greater degree than human activities ever changed the river. Santos's and Weinstein's descriptions, together with ecological analyses of the Amazon and its tributaries by Nimuendaju, Palmatary, Lathrap, Sioli, and Fittkau, provide data and conceptual tools to construct a model of how space, topography, biology, and demography in the Amazon interacted with, responded to, and influenced industrial growth, technical innovation, international trade, and the geopolitics of the world-system.

In *Underdeveloping the Amazon* (Bunker, 1985), I elaborate such a model as a sequentially cumulative series of socially organized extractive cycles molded interactively by (1) technological, geo-political, and market transformations within the world-system and (2) the demographic, ecological, political, and economic conseqences of local social efforts to take advantage of the opportunities these changes in the world-system created. Local spatial and material configurations constrained both local and world-systemic actions in each cycle. My strategy was to extend the mechanisms of stages of autocatalytic diversification and growth that underlay models of ecological succession to include the sequentially accumulated ecological and social effects of each extractive cycle on both the social and natural resources available in subsequent cycles.[4] The following sections detail how local and international actors in these successive extractive cycles responded to and mediated between the changing technologies and markets of world capitalism on the one hand, and the local spatial and material features that formed the substance of their participation in the world economy.

4. The term "sequentially cumulative" emerges from my reading of Arrighi's (1994) demonstrations that each systemic cycle of accumulation incorporates and surpasses the expansion achieved in the earlier one it superceded. This idea is remarkable similar to classic formulations of ecological succession.

SPACE IN THE GEOPOLITICS OF COLONIZATION AND IN THE SUBORDINATION AND DECIMATION OF INDIGENOUS POPULATIONS

The Portuguese first settled and fortified the Amazon because it provided a hydrologically defined space available to Dutch fleets to penetrate the sugar plantations of the Northeast or to Portuguese fleets to protect that commercially profitable space. In order to cheapen administration and defense of the Amazon, the Portuguese crown ceded huge concessions of land and rights to indigenous labor to its officers.

The Amazonian space was not appropriate—biologically, hydrologically, or climatologically—to the technologies or to the labor relations preferred by the Portuguese. Portuguese economic exploitation of the Amazon was never profitable enough to purchase or to sustain imported labor. Instead, the Portuguese enslaved the indigenous population and exploited its captive labor to construct edifices and roads as well as for extraction of forest and river products. Costs of extraction rose and profits fell as these expeditions depleted the most proximate sources of labor and material.

The conditions of work and living in an increasingly impoverished settlement, combined with exposure to exotic germs brought in on ships from Europe, caused numerous epidemics and consequent reduction of native populations. The need to replenish their vulnerable supply of captive labor drove the Portuguese to mount more slaving raids and to provoke slaving wars. These raids and wars drove the remaining indigenous population further and further upriver. This increased the distance travelled on subsequent raids: this increased the need for provisions—for Indian rowers on both legs of the journey and for captured Indian slaves on the return. Both rowers and new captives suffered malnutrition, disease, and death from attempts to economize transport across this ever greater space (Hemming, 1978; Sweet, 1974).

The densest indigenous populations had located in the mouthbays of tributaries to the Amazon, where the calmer waters provided access to fish and turtle protein and the seasonal floods maintained soil fertility. The mouthbays and *varzeas*—spaces with abundant fertile grounds to cultivate and waters to fish—became spaces dangerously accessible to the Portuguese slavers' boats. Portuguese slaving drove the populations that survived war, disease, and enslavement to flee up the tributary rivers, to the less fertile land and the less rich waters of the terra firme. Enslavement, disease, war, flight, and refuge in less fertile environments hugely reduced indigenous populations.

The naturally occurring attributes of space, and of matter within it, had facilitated and enhanced certain human activities such as hunting, fishing, cultivating, and transporting, while constraining other activities, including European styles of agriculture. These same attributes of space structured Portuguese violence and exploitation and indigenous reaction and flight. The interaction between these natural and social forces created a demographic vacuum that seriously impeded local response when technological and industrial changes in Europe and in North America created rapidly growing demand for Amazonian rubber.

HOW SPACE, TIME, AND MATTER STRUCTURED RELATIONS OF PROPERTY, LABOR, AND EXCHANGE IN THE RUBBER ECONOMY

The ravenous demand for rubber started early in the second industrial revolution. European inventors, engineers, and capitalists had found ways that combined iron, coal, and steam to provide matter and energy for machines that performed an increasingly broad range of work. These machines could move far greater loads more rapidly and apply far greater force at much higher temperatures than either human or animal effort could manage. Innovation and capital rapidly extended these functions to the development of machines that transformed iron into other machines.

The firms that pioneered these innovations realized huge and expanding surplus profits; the national economies in which these firms participated realized rapid economic growth. Additionally, the states that directed these national economies greatly increased their revenues and their powers. Control over the raw materials that made up and powered these machines and over innovations that extended their productive use were of critical importance to these states and firms. Many such innovations stimulated discovery and use of new types of raw material; others adapted machines to the physical and chemical properties of the new types of matter discovered or processed.

The iron-coal-steam triad accelerated the historic interplay between technology and capital on the one hand and matter and space on the other. Some of the most rapid and dramatic episodes of this interplay occurred as engineers sought to adapt their machines to the very different chemical and physical properties of different deposits of iron and coal and as states and firms searched for new sources of material. These new sources had to be (1) large enough to sustain the expanding scale of new technologies and (2) of chemical and physical compositions that enhanced the performance of their machines and the quality of the commodities they produced.

Innovations and improvements in these machines and the extension of the kinds of jobs that could be mechanized increasingly required the transmission of motor energy between different planes. Metallurgical techniques were not yet exact enough, nor was machine-tooling precise and standardized enough, to achieve this transmission through mass-produced systems of steel cogs, wheels, and shafts. Flexible belts strong enough to hold their shape and texture through heat and friction were cheaper and more practical. Fabrics and rope tended to slip against restistance, and also wore out fairly quickly. Rubber provided greater strength and grip, but tended to stretch.

The growing importance of steam-driven pumps and motors to business profits and to state revenues from an increasingly mechanized world capitalism stimulated searches for technologies that stabilized rubber even under high temperatures and friction. Goodyear's invention of vulcanization first achieved these goals in 1939. Rubber thus treated served for the transmission of mechanical energy with flexible belts and for tires to allow mobility for these machines. Subsequent research and investments improved vulcanization. These improvements progressively extended the profitable mechanical applications of rubber. At the same time, technical innovations, particularly the invention of the bicycle and the automobile, and then the rapid mechanization of military force, added to the hugely expanding demand for rubber.

The rapid expansion of mechanical uses of steel and the rapid development of new mechanical technologies eventually generated incentives for the invention, fabrication, and standardization of machine-tooled screws, cogs, wheels, and shafts. Once these new inputs were possible, the steel of which they were made transmitted more force, resisted greater heat, and lasted longer than rubber. At the beginning of the machine age, however, rubber's material qualities—both natural and socially improved—allowed less technically demanding performance of these highly profitable functions.

Rubber of a quality found only in the Amazon worked best for these new technologies. Much of the most profitable research into and development of new technologies were thus based on Amazonian rubber. Incremental refinements in this technology combined with inventions of new mechanical applications drove demand for rubber far higher than local labor and transport systems could supply. Prices soared, and the local attempts to respond to this booming demand radically changed the economy, the demography, the politics, and the law in Amazonia. Materio-spatial features of the Amazon and the social and economic history of European responses to them made full response to the soaring demand impossible. Local attempts to corner or manipulate the market made the inadequate supply erratically volatile.

The rubber boom coincided with one of the most dynamic episodes of material intensification and spatial expansion of the world economy. The discovery of vulcanization and the rapid proliferation of new mechanical uses of rubber closely parallelled the development and diffusion of Bessemer conversion for smelting iron, which made durable steel of uniform quality cheap enough for mass production. The introduction of Bessemer steel is generally credited with the rapid ascent of the U.S. economy in the second half of the 19th century. The

U.S. led the world in its rate of adoption of Bessemer converters, and rapidly achieved primacy in both world production of steel and in world extension of railroads. The U.S. had surpassed the longer established steel industries of Britain and Germany by the 1890s, though European steel production was still expanding rapidly.

The new steel-based technologies that depended on rubber provided huge surplus profits and stimulated major economic growth in the rapidly industrializing core, particularly in Britain and in the United States. Industrial firms there, and national states, were intensely interested in the supply and price of rubber, but had to adapt to the materio-spatial, the economic, and the political structures of the Amazon to satisfy their needs.

The local actors who organized to take advantage of the new demand for rubber were directly constrained by (1) the biological characteristics of the rubber tree, *hevea brasiliensis*, particularly as those characteristics determined the spatial distribution of the tree itself and the temporal distribution of the labor process involved in tapping, collecting, and curing the rubber, (2) the course and flow of the rivers that provided the only commercially viable access to the *seringais*, or rubber groves, and (3) the seasonal patterns of rainfall and flooding.

The biology of the trees, and their distribution in space, had evolved to a very wide dispersion of single trees across spaces broad enough to impede the proliferation of *dothidella ulei*, a fungus that would thrive in the presence of thick groves of trees. The sap of this tree dripped slowly enough that only a cup could be collected every second day. Exploiting the rubber trees thus required single individuals to walk great distances between trees to collect a relatively small amount of rubber each day. They then had to cure the rubber and agglomerate it in small daily increments into a large ball for eventual delivery against their debts to the capitalist who had transported and provisioned them.

Just as the high cost and slow speed of animal traction limited the 17th century logging described by Albion (1926) to trees three miles or less from river's edge, the time and effort of carrying latex through the jungle limited the paths, or *veredas*, to distances within an area that a man could tap and carry to river's edge in a day's work. The inward transport of labor and provisions at the beginning of the dry season, and the outward transport of labor and rubber at the beginning of the rainy season, depended completely on the course and flow of rivers; so rivers determined which *seringais* could profitably be tapped. The low density of rubber trees and the restriction of tapping to trees within a day's round-trip circuit from a river meant that response to increasing demand required longer voyages up-river. This increased labor and transport needs and so drove up the costs and prices of rubber.

The absence of human population in this space, result of the earlier exploitation of slaves, imposed the need to transport labor and then to control and discipline that labor across space. The low density of trees, the slow dripping of latex from them, and time-consuming, daily, chore of curing and agglomerating the latex into solid bulks required that labor was widely distributed over long periods of time. Capital had to be advanced sufficient to sustain the workers transported long enough to accommodate the slow, biologically set rhythms of latex dripping and the slow, materially set, process of smoking, curing, and agglomerating it. Control or supervision of this widely dispersed, very slow, labor process would have been excessively costly. Direct control of labor, direct security over the capital advanced for its transport and provisioning, and physical security over its product were all impossible under these conditions.

Time, space, and matter all threatened the capitalist's ability to assure that he could appropriate rubber as return and profit on his investment. Capital was thus impelled to organize the labor process through devices that guaranteed returns on investments in transporting, sustaining, and disciplining isolated laborers at great distance over extended periods of time. One solution was to prevent boats owned by other merchants from providing transport of labor or product to rubber tappers, who might choose to sell the rubber they had tapped and flee to avoid the debt that capital claimed for their transport and provisions. Another was exemplary violence against any such tapper unlucky enough to be caught unprotected.

The rubber traders, or *seringalistas*, devised customs, and the state devised legal forms of property and usufruct, based on the flow of rivers, that designated the owner or lessee of a *seringal* as the sole legitimate claimant to rights of transport on each river. These rights could be enforced by violence. In this sense, the material and spatial natural configuration of rubber trees and rivers created the parameters within which social, economic, and political relations of property, extraction, transport, exchange, and law could be arranged to fit both the local ecological and social situation and the global economic demand.[5]

The same spatial and material configurations that constrained and molded the local organization of rubber extraction also limited and destabilized supplies to an industrializing world increasingly dependent on and enriched by rubber's role in production. The potential for profit in rubber-dependent technologies accelerated even more when bicycles, and then automobiles, entered consumer markets as pioneer instances of machines made as consumer items for end use rather than as inputs for production.

The natural constraints on supply catalyzed both the scientific efforts to improve vulcanization sufficiently to expand the utility of lower grades of rubber and the efforts of the British state and colonial administration to transform the rubber cultivar from a feral resource to a domesticated cultigen. These efforts eventually transformed rubber from a wild plant where British capital "controlled neither land nor labor" to a plantation crop in Asia, where British capital controlled both (Brockway, 1979).

The flood of plantation rubber onto world markets in 1910 reduced the price of rubber below the costs imposed by the widely dispersed distribution of feral rubber trees in the Amazon and the high costs of the transport needed to extract and export it. The ports and boats of the *aviamento* system were too costly to maintain under this new price regime. Most were allowed to deteriorate while their diminishing use values were applied to a vastly reduced trade in rubber, gathered now by autonomous peasants as a supplement to diversified subsistence actitivities.

Space and matter thus defined the mode by which the Amazon was reincorporated into the world system as the source of a critical raw material. At the same time, space and matter created the conditions that eventually led coalitions of social actors in the core to search for technological and organization means to increase and stabilize the supply and to reduce the cost of rubber. Agents of industrial firms and of imperial states collaborated to move its material reproduction and to import colonial populations for its cultivation in these new locations. These initiatives ultimately impoverished the Amazon's economy as rapidly and radically as the local responses to growing core demand had enriched it.

Rubber was not the only input into the rapidly developing iron, coal, and steam-based technologies that so expanded the economies of scale in industrial production and the rates of growth and profit in industrializing nations. The Bessemer process depended on low sulphur ores and fuels and on manganese to combine strength with durability. The rapid expansion of steel processing required mechanization of mining and of loading for transport. New technolo-

[5] The whole system took the name of the Portuguese word for providing (*aviamento*). Merchant capitalists in this system were know as *aviadores*. The rubber grew in *seringais* leased in long-term *aforamentos* to *seringalistas*. The *seringueiros* delivered the rubber they tapped and cured to pay off the debt for transport and provisions. The *seringalista* or the *aviador*, who might or might not be the same person, set the prices for provisions and transport and for the rubber that was delivered against them. Tappers' debts thus tended to be perpetuated across seasons.

gies were developed for stripmining and loading, but at first they required large surface deposits of soft ore. These characteristics—soft, low-sulphur ore in large superficial deposits—were discovered in the iron-ore deposits of the Mesabi range in the Northern Great Lakes region. There, the complex interdependence of natural resource characteristics, topography, hydrology, technology, economies of scale, and massive accumulation of capital supported sustained development around the Lakes, even through the ore-supplying areas suffered relative economic collapse as resources depleted and technologies changed. The deposits on Mesabi, at that time the largest ever exploited, were sufficiently great and sufficiently concentrated to allow science, technology, and capital to discover and implement new economies of scale and speed. These materio-spatial properties of iron allowed owners of mines, ships, docks, and railroads to accommodate the rapid expansion of demand. By the 1950s, decades of intensive exploitation of the highest quality ores had reduced the Mesabi deposits to taconite. This ore is much harder and thus more costly to mine and process than the soft ores that had favored the early technologies of steam shovels, drag lines, and dump loaders. Huge increases in the tensile strength of steel, in the precision of metal and tool working, in the power of motors, and in the efficiency of mechanisms to convert heat energy into mechanical energy and into controlled chemical reactions, had provided capital access to new mine and transport technologies. The economies of scale—particularly in the hull size and strength of boats and in the power, weight, and fuel efficiencies of internal-combustion motors—that these new technologies supported made it possible to exploit Australian, South American, and African deposits. By 1973, iron ore and coal could travel the thousands of miles between these sources and Japan more cheaply than U.S. Steel could move ore from its mines on the north of the Great Lakes to its smelters on the south. Stronger rail systems and more efficient diesel motors made it economically viable to haul huge loads of iron and coal out of mines far more distant from navigable water than the Mesabi deposits are.

These new technologies, combined with the continued discovery of larger deposits of higher grade ores in places so far from industrial centers that earlier transport technologies left outside the sphere of competitive exploitation, obviated any impulse for capital to support technical searches for a material substitute or alternative means of procurement for iron, These same technologies and discoveries interacted with the ways that geology and chemistry had distributed iron and coal deposits across the globe to create a strong impulse to cheapen transport of bulky material across wider spaces. U.S. Steel suffered devaluation of the capital it had invested in infrastructure and technology appropriate to the chemical composition of the Mesabi ores and to the size of ship that could sail on, and between, the Great Lakes. The steel industry of Japan, Europe, and

Korea, however, exploited the cheapened transport of matter over greater distances, increasing both the material intensity and the spatial expanse of steel production.

In comparison, the dispersal of rubber trees and the slow biological rhythms of their internal circulation of latex so constrained tapper's and trader's ability to expand supply that consuming firms and states collaborated to alter the spatial, and thus the social and political, features of rubber production. States and firms were later impelled to change rubber's material features as well. U.S. and German efforts to circumvent the impediments of intercore wars on their access to Asian plantations accelerated their search for techniques to fabricate rubber synthetically from petroleum. Their success expanded the supply and reduced the price of raw material essential to the huge cheapening and expansion of automobile, truck, and airplane traffic after World War II. It also further depressed the price of natural rubber.

TOPOGRAPHY AND HYDROLOGY IN THE EXTRACTION OF PLANTS AND ANIMALS

Multiple studies of floral and faunal extraction in the Amazon provide complementary perspectives on the ways that matter and space first mold local responses to world-system demand for new resources and then structrure the ecological and social conseqences of these local responses. Data presented by Alden (1976) and by Sweet (1974) on the extraction of rosewood and cacao; by Nigel Smith (1974, 1980–81) on the extraction of turtles, manatees, and caymans, and the consequent impoverishment of biological energy capture and exchange in river and varzea; and in Fittkau's (1973) analysis of the spatial and material functions of the cayman in maintaining the fertility required for fish in the mouthbays of the tributary rivers all indicate the autonomy of natural spatial and material systems in the Amazon and the extent to which successful human extraction from these systems must adapt to them. The human activities may have profound, complex, and unpredicted consequences upon these systems, but these consequences themselves occur through the dynamic natural interactions of spatial and material processes, however much human intervention may have catalyzed these changes.

IMPLICATIONS OF AMAZONIAN EXPORT CYCLES FOR MATERIO-SPATIAL ANALYSIS

Human endeavors to exploit the resources produced in specific locations can only succeed if they adapt to the material and spatial features of those locations. In all of the Amazon's extractive cycles—the slave wars, the trade in turtles, fish, cayman, manatee, and capybara, the rubber boom and its eventual decline—the river system as a hydrologically, topographically, materially and biologically differentiated space created the conditions for the reproduction of the resource extracted and the means of its transport. The hydrology and the topography of the river directly shaped the human activities aimed at profitable extraction. In the case of rubber, they directly limited the speed and proliferation of core technological innovations that incorporated rubber into an expanding range of increasingly productive and profit-generating machines. The materio-spatial attributes of rubber and of the river system that conditioned its natural production and commercial access to it affected the economic opportunities and the social and political organization of firms and states in the industrializing nations as much as of local merchants, rubber-tappers, boat owners, and politicians. The ways they affected these different social groups, however, and each group's behavior in response, varied enormously according to their different positions in relation to these materio-spatial characteristics and to the technical and economic processes these characteristics gave rise to. The consequences of these actions—their costs and their benefits—were unevenly distributed in the same way. In this sense, the dynamic, sequentially cumulative processes of technological and social organization innovations in extraction, transport, and processing of matter emerge from reciprocal and interactive dynamics between local and global instances of nature and society.

These reciprocal dynamics belie notions of the social construction of nature and of space. Humans do not transform or construct space socially; at most they accelerate and intensify their own transit and their transport of matter across it. Time does not annihilate space in this model, rather space as condition of production provides opportunities, and space as obstacle to and cost of transport constitutes the challenges, that foment innovations in social organization and technology.

My attempts to model these dynamics originated in the Amazon, where they are eminently salient and therefore visible. In the following sections, I will endeavor to explain how I have attempted to carry this model forward into an explanation of how space and matter—as the contradiction between the cost of distance and economies of scale—have driven the progressive globalization of capitalism. I will show how the tension between economies of scale and the cost of space creates technical and organizational challenges that foment social, political, and economic, and technological innovations. Implementation and extension of these innovations have expanded the productive and commercial space and the transformation of matter in each systemic cycles of accumulation (cf. Arrighi 1994).

The long-term, sequential cumulation of these transformations constitute the underlying mechanisms of globalization. I will maintain a focus on the global

consequences of local processes in the Amazon to demonstrate that even as the outcomes of these processes become global, their origins are rooted in locally observable and specifiable materio-spatial features. These features present the challenges and the opportunities that generate the economies of scale in transport and in technology that have driven the centuries-old progress of globalization.

The core explanatory mechanism in this model relates the succession of materio-spatial configurations in Amazonian extractive economies to the timing and material needs of technological innovations. The timing, as well as the sequentially cumulative scale, productivity, and profitability, of these innovations both drive and reflect the material intensification and the spatial expansion of the world capitalist economy.

This sequence of new technologies intersects and interacts with material resource discoveries in particular spaces. These discoveries often motivate or accelerate the incorporation of previously external peripheries into the world-system. Local actors—sometimes indigenous or previously resident, but often immigrants responding to the economic opportunities the recently discovered resource provides—drive political, social, economic, and financial reorganization in their endeavors to profit from these new demands. Their profits depend on adapting to and exploiting the materio-spatial features of the resources in ways that satisfy the technical needs of the processes of production and the financial needs of the states and firms that control these techniques.

Local elite responses to the pressures and the opportunities that the expansive and technically driven world-systemic demand for raw materials creates change the ecology that they are exploiting, generally reducing its capacity to keep up with that expanding demand. When the lag between global demand and local supply becomes too great, firms and states of the industrial nations choose among and combine several different strategies. These include: (1) searches for new sources, generally larger and with physical and spatial characteristics more compatible with new industrial demands, (2) technical innovations that cheapen access to these new, larger sources, and (3) invention, improvement, and cheapening of synthetic substitutes. Each of these alternatives materially intensifies and spatially expands the world economy while devaluing the capital the local economy has sunk into adapting itself and its environment to world-system needs for its resources.

I used the empirical narratives of the boom and bust of each of these extractive episodes to model the materio-spatial consequences of depletion and of diseconomies of scale in most extraction. From these narratives, I deduced that states and firms in the core mobilized science, commerce, and imperialist or colonial forces to resolve problems of rising cost, scarcity, or inconsistent supply to (1) find another or other sources of the raw material in question in other locations and to organize or catalyze the transport systems that would ensure a cheap and steady supply of these materials across the spaces thus incorporated into the world-system, (2) find natural or devise technical or synthetic substitutes for the raw material in question, as happened with the technologies that substituted petroleum for many of the uses of oils provided by, inter alia, manatees and turtles, and for many of the uses of rubber, or (3) domesticate and convert to plantation cultivation the natural or feral sources of the raw material, and import or organize a population sufficiently controllable to provide a cheap and stable labor force, as happened with cacao and with rubber.

All three of these solutions manipulate material process, both natural and social. They relocate sources according to social (i.e. demographic, political, and geopolitical) and natural (i.e. climatological, podological, and geological) attributes as these relate to the material requirements of the reproduction and extraction of the raw material and to the spatial, topographic, and hydrological determinants of the cost of access and transport. All three of these solutions provide mechanisms to explain the secular spatial expansion and material intensification of world-systemic production and exchange.

I used this spatio-material model to organize my analysis of the local consequences, environmental and social, of each extractive economy and of the changing demands for raw materials in the world-system, but I abstracted these processes upward into a thermodynamic model of unbalanced energy flows to account for the systematic underdevelopment and instability of extractive economies.

After finishing *Underdeveloping the Amazon*, I started to work on the implications of this model for Marx's theory of rent. I found David Harvey's (1983) otherwise very helpful discussions of rent and of the built environment too compromised by his focus on finance and on urban phenomena to apply directly to material analysis. At Johns Hopkins, two of David Harvey's students, Kevin Archer and Michael Johns, took a seminar in which I was trying to work on these problems. Michael and Kevin challenged and pushed me toward a more nuanced interpretation of Marx's views of use values and their transformation into exchange values.

During that same period, Martin Katzmann's (1987) extended critical review article of *Underdeveloping the Amazon* appeared. This was essentially an encyclopedic summary and critical deployment of neo-classical resource economists' claims that vent-for-surplus of natural resources was a regular and reliable means for the economic development of "newly settled" frontiers. Simultaneously, Robert Volk (1986) claimed in a review that Marx's labor theory of value provided all the mechanisms required to explain why "enclave economies" led to unequal development.

These challenges from the left and from the right, and the directed reading of literature I had previously ignored that Katzmann's bibliography led me to do, drove me to search for the reasons that some extractive peripheries, most notably the United States, but also Sweden, Denmark, parts of Germany, Canada, and Australia, had subsequently industrialized sufficiently to achieve at least partial participation in the core. I gradually became convinced that notions of unbalanced energy flows were too abstract and too aggregated to permit analysis of the specific binary and multilateral production and exchange relations that structured and periodically reorganized the world economy. The physical and chemical attributes of raw materials, and their location in space as mediated by topography, hydrology, geology, climate, and biology provided much more direct bases for explaining the social and geopolitical strategies for the extraction, transport, transformation, exchange, and consumption of the secularly expanding diversity and volume of commodities.

The deployment of these strategies necessarily intersected with the economics and geopolitics of space. This intersection implied that materio-spatial mechanisms aided not only in the explanation of specific economic strategies, but also underlay the ways that these strategies molded social structure, agency, and organization from local to global levels.

Wittfogel's compilations of Marx's analsis of natural systems in the production of use values, my own readings of Marx's theory of rent (Bunker, 1986, 1992), and Carolyn Merchant's (1983) discussion of Francis Bacon's and Agricola's views on the imperative that all human uses of natural systems succeed only as their technology responds to material and chemical attributes of these systems, all point to the ways that the physical and chemical attributes of different kinds of matter enter into all human technological improvements. The very diversity of matter dispersed across space provides the material and spatial means of the secular intensification, proliferation, technification, and expansion of both types and volume of material production that drive the system's dynamic of growth and change. These considerations convinced me that Wallerstein's tripartite categorization of the world system, and his tendency to use a categorical logic instead of materially and spatially grounded mechanisms to explain the dynamics of growth and change, impeded an adequate specification of particular or local economies.

Harvey (1983) elaborates his own concepts of the built environment combined with a synthesis of van Thunen's central place theory into an appreciation of Marx's theory of rent. In this effort, he explicates Marx's insights into capital's dependence on the state to redistribute the huge sunk costs of transport technologies and infrastructure to include the various economic and social agents that benefit from them. Marx was very clear that these sunk costs had hugely expanded as coal, iron, and steam made new transport means possible and then provided use values that could only be realized as these new transport technologies moved them cheaply in bulk from their dispersed locations to the increasingly agglomerated urban-industrial centers that machino-facture brought about. Because Harvey is so focused on the internal dialectic of capital, however, he does not fully appreciate the extent to which Marx's rent theory specified the social and political implications of his abstract affirmation that nature and labor are inextricably interdependent in the production of commodities.

Harvey's insights into rent, transport, and the built environment complement Innis's (1933, 1956) conceptually different but analytically complementary explanations of the costs, dynamics, and political/organizational consequences of transport systems devised to satisfy core demands for peripherally extracted raw materials. Reading Harvey and Innis together helped me to extend and refine my notions of transport systems as a capital-intensive, debt-creating, state-forming instruments to articulate dispersed site-specific raw material sources with concentrated centers of industrial production, capital accumulation, and political power. Materio-spatial analysis of the financing, construction, and use of specific transport systems' technology and infrastructure in specifiable times and places reveals the specific interests and activities of different groups in both core and periphery. Such analysis can explain how transport technology and infrastructure progressively cheapened and accelerated the consumption of natural resources in each cycle of world-systemic material intensification and spatial expansion.

Materio-spatial analysis of (1) specific extractive economies and political formations of peripheral zones, (2) the technologies, composition of capital, organization of labor, and state formation and reformation in core economies, and (3) transport and communication systems that facilitate and cheapen the flow of material and information between them reveal how these processes have driven progressive globalization. These attributes, and the secular evolution of the technological and political systems they generate, mold the strategies, costs, spatial extent, and profits of core initiatives to exploit multiple diverse peripheries for their varied natural resources. The transtemporal continuity of interactions between social, spatial, and material systems explains the sequentially cumulative processes that have expanded and intensified productive and commercial relations through each systemic cycle of accumulation.

This continuity belies any claims that globalization is a novel or recent phenomenon(cf. Sklair, 2000). Rather, it is the latest and perhaps ultimate stage in spatio-material processes that have evolved and accumulated sequentially through the specificable diverse activities and interactions of specifiable and locatable groups and organizations (Bunker, 1996; Bunker and Ciccantell, 1995 a, 1995 b, 1998, 2000, 2001; Ciccantell and Bunker, 1997, 1999). Paradoxically, it is only called globalization as these processes reach their global limits.

The sequence of Amazonian extractive cycles parallelled the trajectory and and reflected the technologies of production and transport in each systemic cycle of accumulation that occurred during the four centuries of Brazil's incorporation into the world system. The initial settlement and slave wars responded to Dutch-Portuguese struggles for trade dominance, both in sugar and in iron manufacture used for trade with indigenous groups (Sweet, 1974, Bunker, 1982). Destructive exploitation of turtles responded to luxury demand for combustible oils and for self-preserving meat for long, wind-driven ocean voyages before industrial technologies could convert petroleum into light, refrigeration, and motor power. The rubber economy's rise and fall coincided with and contributed to the apex of Britain's industrial and commercial dominance and with the rise of the American challenge in heavy industry. With the collapse of the rubber market and the dominant technologies' increasing use of mineral rather than vegetable matter as primary inputs, the Amazon remained little linked to world markets from 1920 to 1950, when the geo-politics of the cold war and the crucial role of steel in the post-war reconstruction of the European economy generated U.S. political and commercial interest in sources of manganese outside of the Soviet Union. Politically and economically powerful Brazilian groups responded to Bethlehem Steel's blandishments, forming a large company with substantial Brazilian government guarantees of U.S. Ex-Im Bank loans to export manganese from Amapá, the isolated and sparsely populated territory on the northern shore of the Amazon delta.

Manganese is an essential component of both Bessemer and open-hearth steel making. It is used in relatively small proportions to coal and iron—14 pounds per ton of steel—and is priced high enough that transport from the most remote parts of the globe was commercially viable. The Serra do Navio deposits were highly concentrated in an area 20 miles from a deep water port. Construction and then operation of mine, railroad, and port generated considerable prosperity within this coastal enclave and huge profits for the concentrated capital that controlled it, but these effects were spatially and materially more limited than the effects of the rubber boom had been.

The parallel trajectories of (1) technologically-driven, scale-augmenting, sequentially cumulative cycles of material intensification and spatial expansion in the world economy and (2) demand-driven extractive economies of the Amazon crystallized in 1985, when, 20 years of complex political and economic negotiation and struggle after its initial discovery, Carajás, the largest iron mine in the world, commenced operation. The Companhia do Vale do Rio Doce (CVRD), a public/private Brazilian firm that already exported more iron ore than any other company in the world, owned, constructed, and operated the mine.

Construction absorbed the largest international loan for a mining project in history. Much of this capital was invested in the longest rail line and the highest capacity port in the world dedicated to a single mine. The determining criteria for the size of mine, port, and rail appear to have been the economies of scale required to compete in Japanese and European markets. These economies of scale had to be huge to overcome the diseconomies of space in constructing and operating a mine located 900 kilometers through dense rain forest and across multiple rivers from the nearest deep water port and producing such a high-volume, low-value commodity as iron ore. Even after the long and difficult haul through jungle, the port was still further from Japan than coal or iron had ever been commercially transported before. The design, finance, construction, and operation of the Carajás mine represented the latest step in the globalization of iron and coal markets by technical advances in the scale of mining, transport, and processing. Together with oil, these two materials are among the most voluminously consumed in industrial production. Competitive industrial performance therefore requires that they be relatively cheap. Even before iron and coal became globally sourced and traded raw materials, transport usually constituted over half of their landed cost. The technological innovations and economies of scale in mining, in transport, and in production that made Carajás iron ore competitive in Japan were also a major ingredient in globalization.

Far more than the international conspiracies of firms and states to assure a cheap and steady supply of rubber, this globalization of iron markets emerged from complex processes of collaboration and competition between firms and states in the core as they catalyzed and interacted with local actions and initiatives to adapt to and exploit the materio-spatial characteristics of the new extractive periphery. Contradictions between the ISI principles and ideologies of peripheral nations and the FDI strategies of U.S. based multinational firms had led in the 1960's to broad resource nationalism and to nationalization of many mines and processors. These trends deterred major mining companies from investing in exploration or in new projects. The World Bank, responding to core-wide concerns about potential raw material shortages, mobilized its own technical, financial, and diplomatic resources to coordinate and supplement loans from the U.S., Japan, Germany, the European Union, and Korea to bring the Carajás mine into operation.[6] The majority of this loan was to pay for the huge infrastructural

6. The timing of World Bank intervention and participation in the loan negotiations in 1982 and the Bank's willingness to relax its procedures to link disbursement of the

costs of transport, 890 kilometers of rail through the jungle and a deep water port capable of handling and loading 400,000 dwt boats at the coast.

The unprecedented size of this loan was proportional to the unprecedented scale of the mine and of the processing and transport infrastructure it required to export its iron. The scale of this infrastructure was designed around (1) spatio-material attributes of the iron ore deposit, (2) material and ecomomic attributes of the iron itself, (3) spatio-material and economic characteristics of the potential demand for and the eventual price of iron, (4) the economies of scale in transport that had brought about and were made possible by the latest stage in the material expansion and spatial extension to a global and ocean-based, rather than regional and land-based, market for coal and iron (Bunker and Ciccantell, 2001).

Within the Amazon itself, the proposal to construct this infrastructure had generated an intense polemic. The Tocantins river flowed 150 kilometers to the East of the Carajás deposits, through groves of Brazil nut trees (*Bertolensis excelsior*) whose products were shipped down the river for export from the port of Belém, the capital of the State of Pará. Original plans for exporting the iron through a partnership of US Steel and CVRD had specified a rail line from the mine to the river, barge transport to Belém, and reloading onto ocean going ships at Belém. U.S. Steel strongly opposed CVRD's preference for the much more costly project whose funding the World Bank eventually coordinated. Instead of going out through the river port of Belém, the iron would be exported from an ocean port in Maranhão, thus depriving the state of Pará of both the direct taxes and the indirect income that export from Belém would have provided.

Interview and archival research in Rio de Janeiro, Tokyo, and Washington D.C. on the origins of this controversy strongly suggested that CVRD and the national state had been induced by Japanese and, to a lesser extent, European, interests to support the coastal rather than the river option for export. Belem's port, at most, could accomodate 40–60,000 dwt boats; Maranhão could potentially handle over 400,000 dwt. Exports to US Steel in the United States would not travel long enough distances for the economy of scale in boat size to offset the additional fixed and demurrage costs of the larger ports.[7] European and Japanese

loan to completion of sequentially specified stages suggest that Bank efforts in this case may also have aimed at making Brazilian default on loans less likely.

7. The materio-spatial regularity in this case is that the water resistance again the hull increases as the square of the depth of the hull, while the volume of cargo increases as the cube of the depth of the hull. Fuel requirements per unit of cargo thus reduce with increased size of ship. At the same time, labor requirements increase proportionally less than ship size. These two constants create consistent economies of scale in shipping.

ports were sufficiently distant to do so, however. CVRD bought out US Steel's share in the partnership in 1977, for a payment of 50 million dollars.

CVRD, with World Bank support, thus played into and exploited Japan's strategies to dominate world steel and shipping markets. Japan's moves to dominate these trades eclipsed the formerly dominant U.S. steel and transport sectors. The technologies of mining, transporting, and smelting that had responded to and been fueled by the topography and geology of the Great Lakes region a century earlier were now constrained by these materio-spatial features to compete with the huge boats that deep water ports could handle and the enormous machines that the Carajás deposits could support.

CVRD's actions in these controversial undertakings demonstrate simultaneously, (1) the spatio-material processes and considerations that structure inter-core competition and collaboration and their effects on materially and spatially differentiated peripheries, (2) the consequential role of preferences and decisions of peripheral actors in the restructuring of peripheral-core relations,[8] and (3) the impacts of increasing economies of scale in the extraction, transport, and processing of the most voluminously consumed raw materials on the episodic, but cumulative (cf. Arrighi, 1994) spatial expansion and material intensification of the world-system through succession of distinct systemic cycles of accumulation.[9]

The materio-spatial processes and relations that thus structured political, economic, and financial relations around the social construction of plant and

These economies of scale are offset, however, by the much higher sunk capital costs of the infrastructure required for docking and loading cargo and for the greater costs of in-port delays incurred by a larger, more costly ship. The economies of scale are thus only realized where the voyage itself is long enough to offset the extra fixed costs of in-port handling.

8. Note the CVRD's preferences affected not only Brazil's position in the world system, but the entire world market for iron and steel. The addition of Carajás increased world supplies to a highly inelastic market, with implications for all exporters of iron and for all industrial processors of steel.

9. Japanese pariticipation in this multilaterally shared loan was itself a new step in the strategies to reduce capital exposure and risk through joint ventures and long term contracts that the Japanese had perfected in their dealings with Australia. In this case, the Japanese succeeded in extending the oversupply from excess capacity in world mines at proportionally small proportions by responding to and participating in the core-wide preoccupation with resource scarcity (Bosson and Varon, 1982; Bunker and Ciccantell, 2001)

transport infrastructure coincided with massive scale expansions in different core nations' steel industries. These included: (1) the peak of Japan's expanded production of steel and of ships to dominate world trade in both sectors, (2) Korea's entry into the world steel market through the construction of the largest integrated steel plant in the world, (3) European steel companies moving their processing plants to coastal locations apt for the larger scale of smelting and transporting that they needed to compete with the drastic cost and price reductions of steel achieved by the Japanese and the Koreans (Jornmark, 1993), and (4) the Plaza accords.

The scale expansion and relocation to coastal sites of the Japanese, European, and Korean steel industries and boat construction directly drove the spatial expansion and material intensification of raw materials markets, while the Plaza Accords enormously raised the exchange rates of the Japanese yen, increased the interest and capital costs of all loans made in yen, and lowered the real value of international sales of iron, which were transacted in dollars. The excess accumulation of liquid capital in Japan that led to the Plaza Accords (Murphy, 1996) was itself initiated by Japanese success in reorganizing the spatio-material distribution and the social organization of world metals markets in ways that fostered Japanese dominance of world steel and merchant marine markets. The cumulative result of these interdependent financial, spatial, and material transformations was the enhanced subordination of raw materials exporting peripheries to raw material importing nations of the core (Bunker and Ciccantell, 2001).

This subordination, however, involved the decisions and active participation by local agents in the creation of the capital-intensive infrastructure and adoptions of new technologies with massive economies of scale in mining and transport that supported the core advances in the scale of smelting and refining. CVRD decided to respond to the opportunities these new technologies opened in the Japanese market and to the facilitated access to huge credits opened by the coincidence of the world debt crisis and core country worries about future raw materials shortages by contracting huge loans to (1) increase the extractive capacity of the mine, (2) build the high-capacity rail line to the coast, (3) develop a port adequate to take boats so big that only Japanese ports and the port of Rotterdam could unload them and (4) engage in joint ventures with Japanese firms in ore carriers of over 450,000 dwt.

SPATIAL CONSEQUENCES OF LOCAL DECISIONS TO EXPLOIT GLOBAL MARKETS

At the site of the mine itself, and along the line of rail, the materio-spatial, topographic and hydrological features of the deposits intersected with the temporally conditioned cost of the capital required for the scale of plant and transport infrastructure chosen by CVRD. This intersection of natural and social forces constrained CVRD to coordinate the construction of all phases of the operation so as to come on line as simultaneously as possible. No component of the system could function until all were in place, so temporal disjunction in their completion would increase interest costs on what was in any event an enormously costly sinking of capital. The combined pressures of material, temporal, spatial, and financial dynamics led to a highly lumpy, concentrated use of labor in a relatively restricted space. This prompted both formally managed and spontaneous migration of labor to Marabá, the *municipio* where Carajás was located.

Marabá was then the major source of Brazil nuts and the center of a local trade organized to export them. *Bertolenis excelsior*, unlike *hevea brasiliensis*, grows in dense groves and yields its fruit in the rainy season, when water filling the drip-cups impedes the collection of latex. In other respects, though, the spatio-material features of the *castanheira*, or Brazil nut tree, favored the adoption of the basic material, financial, and social relations of the *aviamento* system. As in rubber, the trade was organized into large *aforamentos*, or long term leases from the state, held in such a way as to allow potentially violent control over access to and transport out of the groves. This system of property and labor relations evolved to permit the *aviador* to appropriate the harvest in order to secure the return and profit on the capital advanced to transport and sustain labor during the months of the harvest.

Migrants who failed to find employment in mine and rail construction, and later employees who were dismissed when all of the huge construction projects finished at the same time, could instead occupy and exploit the lands in and around the Brazil nut groves. The trees themselves depend biologically on the clustering of other trees both for protection against wind and to support a bee essential to their polination. Thus any agricultural use of land in or near a grove can drastically reduce the production of Brazil nuts. The *castanhaleiros*, or owners of the long-term leases, publicly announded that they would respond violently to any challenge to their control of property and of labor.

The state had established a fiscal incentive program to attract businesses that would share some of the infrastructural costs of the transport system. Violent conflict over land and resources threatened to disrupt the smooth implantation of the mine and of the other enterprises that CVRD and the national state were hoping to promote around it. The state responded to this threat by establishing GETAT, a land-policing quasi-military organization with extraordinary powers and authority. GETAT preempted the local state's ownership of the Brazil nut groves and thus its political capacity and authority in Marabá.

As in the rubber economy, the materio-spatial characteristics of the Brazil nut economy directly influenced political and legal institutions and processes.

The initiation of the iron mining economy, however, brought political, economic, and legal processes that were fundamentally at odds with those of the Brazil nut economy into the same space. The Brazilian national state, under intense pressure from CVRD and from Japanese financial and planning agencies, intervened to reduce the autonomy of the local state and of the municipio of Marabá, as well as to restrict the political power of the old Brazil nut oligarchy.

Local response to Japanese raw materials access strategies brought another, quite different, material process into this space. CVRD accepted an invitation to form a joint venture in an alumina refinery and aluminum smelter downriver from Marabá. The Brazilian government, and the public electric company, Eletronorte, were induced to build a huge hydroelectric dam across the Tocantins River to supply the aluminum smelters with cheap electricity. The Japanese government offered at first to participate in the financing of this dam, but after the Brazilian government was publically and fiscally committed to the project, the Japanese withdrew their offer, alleging that the project they had themselves proposed was not economically viable. Eletronorte assumed huge debt to finish the project, and guaranteed long-term prices for the electricity transmitted that turned out to be well below the cost of production and interest charges.

Rising energy costs in Japan had induced the Japanese state and Japanese firms to collaborate in moving the energy intensive aluminum industry out of Japan through joint ventures with national states that controlled large sources of bauxite. Because bauxite forms through the percolation downward of aluminum and the dissipation of the water-solvent silica that bonds to it, the richest deposits occur in flat areas in the humid tropics. Hydroelectric dams in narrow steep valleys provide the cheapest sources of the huge amounts of electricity required to separate the high valence oxygen in aluminum (AlO_3). Locating an aluminum smelter near a bauxite mine therefore makes little economic sense. The hydroelectric generation of the energy required to smelt aluminum near the best sources of bauxite require huge amounts of water spread over huge areas to compensate for the low height of dams in these relatively flat areas.[10]

Agencies of the Japanese state and of the Japanese aluminum industry, however, manipulated Brazilian aspirations for industrialization of the Amazon to gain local political and financial commitment to building these dams. They contracted a reputable and well-staffed development consultancy in Tokyo to carry out and publish an analysis of the economic and social benefits of electric genera-

---

10. The amount of energy generated is a direct function of the volume of water times the height of the dam (Kw=VH).

tion in the region. These same studies also described ways that the dams would facilitate commercial transport on the "hydrovia" that they would make possible. They propogated the idea that the hydroelectric dam constructed for a regionally vertical integration of all three phases of aluminum production—mining, refining, and smelting—would promote additional industry through induced linkages to both aluminum ingots and the electricity. The Japanese contrived to reduce the cost to themselves of building an economically inefficient dam by inducing Brazil to assume most of the equity costs of these undertakings (Bunker, 1994 a, b). Electronorte was able to provide the transmission lines to the smelter, but could not then afford to extend lines to established communities. No locks were built around the dams, so they impede the local transport they originally promised to enhance.

At the time, the aluminum industry was controlled by six huge firms who used their oligopolic power to keep prices up by keeping supply well below demand. The history of these high prices influenced Brazil's state to accept the high capital costs of building the dam. CVRD agents were apparently not fully aware that the Japanese state and the Japanese aluminum industry were engaged in similar joint ventures with six other nations at the same time. These multiple joint ventures in smelting all came on line at about the same time and vastly oversupplied the market, leading to the price crash of 1982 (Bunker, 1994).

The Japanese strategy essentially involved an inversion of the materio-spatial logic of the aluminum oligopoly, which had located smelting, the most expensive and capital intensive phase of processing, in the industrialized countries. The Japanese strategy was to promote joint ventures with national states where bauxite was abundant and who might be induced to generate and sell electricity cheaply.

By manipulating the resource nationalism and desire for industrial development of bauxite-rich nations, the Japanese relocated the capital intensive—and energy intensive—phases of the industry to the periphery at the cost of the peripheral nations. The Japanese promulgated an over-simplified, wildly optimistic version of the vent-for-surplus notions that capital from raw materials exports could be invested in processing and transformation in such a way as to "capture" the linkage or spread effects of these materials. The Japanese incorporated these ideas into elaborately prepared and widely distributed technical studies of and projects for ways to maximize economic development through investments in natural resource extraction and processing, transport infrastructure, and hydroelectric generation. Japanese firms and agencies of the Japanese government combined these studies[11] with offers of participation in infrastructure and joint ventures in plants to induce the states of aluminum rich nations

to invest in dams and smelters (Bunker, 1989, 1994; Bunker and O'Hearn, 1992). National, state, and provincial governments in Indonesia, Venezuela, Australia, Canada, and Brazil were all seduced by Japanese offers to exploit their hydroelectric potential to smelt aluminum.

Japanese initiatives had catalyzed the globalization of iron and coal extraction and export by stimulating states and firms in distant source nations to invest in mines and transport in order to supply cheap raw materials to increasingly centralized, scale-economic smelters in the core. In aluminum, the tactics were inverted but the consequences were the same. Japanese initiatives globalized production by decentralizing what had been a highly concentrated, monopolistic system of smelting to the sites of raw materials supplies. Both strategies expanded the commercial arenas of these metals—creating excess capacity and cheap transport—at the cost of the supplying nations.

The Japanese found willing collaborators in promoting these ideas, particularly in CVRD and in those ministries of the national state that were primarily concerned with finance and foreign trade. Multiple decisions at the local level were the necessary conditions for the spatial expansion, material intensification, and organizational and financial transformation that globalized the world's aluminum industry. As does the case of Carajás and the decisions about the scale of its infrastructure, the bauxite-aluminum project rewards integrated analysis of local and global instances of materio-spatial process. Again, the local process is not simply an instance of a reflex of a global phenomenon, but directly drives the transformation of the global system.

In the course of these conceptually interdependent projects of research and analysis, I discovered that I could not understand the materio-spatial dynamics of extracting and processing iron and aluminum in Brazil without first understanding how the Japanese firms, sectoral associations, financial institutions, and state agencies had transformed and globalized raw materials markets (Bunker, 1992, 1994; Bunker and O'Hearn, 1992; Bunker and Ciccantell, 1994, 1995a, 1995b, 2000, 2001; Ciccantell and Bunker, 199, 1999, 2002). As I investigated Japanese raw materials access strategies, however, it also became clear that to succeed they had to remain highly responsive to local phenomena—political,

11. The study proposing the construction of a hydroelectric dam to serve the aluminum smelter in the Amazon ran to seven volumes, printed on glossy paper with ample tables, graphs, and photos.

cultural, physical, chemical, and topographic.[12] These strategies had to adapt simultaneously to (a) the physical, chemical, and spatial features of the material itself; (b) the patterns of world supply, demand, price and spatial organization in the world market; (c) the political organization, political culture, and economic-policy ideologies of the exporting nations; (d) the market as structured by earlier dominant economies; and (e) the responses of the exporting nations to the specific measures the Japanese took to restructure the market to their own advantage (Bunker, 1994).

CONCLUSION: TRANSTEMPORAL COMPARISONS OF SPATIO-MATERIAL PROCESS IN MOVING FROM LOCAL TO GLOBAL

Each of the cases I have summarized here shows how local materio-spatial relations and processes in the Amazon intersect with, and partially constitute, the world system as it transforms, and is transformed by systemic changes in cycles of accumulation. Attention to materio-spatial attributes is necessarily ideographic and complex, but the discrete natural—physical, chemical, geological, hydrological, climatological, etc.—features of specific sites and the discreet social relations—technical, economic, financial, etc.—that respond and adapt in order to exploit them each manifest regular underlying processes and mechanisms. These regularities and mechanisms have different explanatory status; their potential generality varies accordingly. These variations are not an impediment to comparative historical analysis; rather, their different explanatory statuses allow analysis of the relative weight of the various natural and social factors as their interaction brings about site-specific and global economic and ecological change.

Identification of these regularities and mechanisms can thus support comparative analysis across material types and across time. Materio-spatial analysis provides a means to compare conjunctures across the cumulatively sequential changes in technology, production, and institutional density—both of state-firm relations in specific social formations and of the world system itself.[13]

---

12. Japanese negotiating strategies varied in Australia and in Brazil in ways that simultaneously took into account the very different relations of central and local state power in the two countries and the differences in distance between iron mines and the ocean(Bunker and Ciccantell, 2001).

13. Comparison based on site-specific intersections of materio-spatial regularities allows transtemporal comparisons that supercede Millian strictures that require control of all but one variable. Such comparison allows configurational (Tilly, 1995) and

Incorporating the specific materio-spatial attributes that determine how diverse specific raw materials and the sites from which they are extracted participate in and affect the world-system requires a range and scope of empirical and analytic work beyond any individual's capacity. That is, the ideographic requirement of specific detail in such analysis excludes any possibility of scholarly achievement in splendid isolation. My own inspiration and instruction in this approach is deeply rooted in other people's field work and writing on specific times and particular events in particular places in the Amazon.

Susanna Hecht's (1985) integration of material properties of soils, trees, grasses, and beef cattle into the political economy and spatial parameters of Brazilian fiscal incentives for ranching and the politics of land use serves as a stellar model of the intersection of physical and social phenomena. Timmons Roberts' relation of subcontracting and other informalizing labor relations to the spatio-material requirements of the Carajás deposits and his subsequent work with Peter Grimes on the interactions between the economy and the ecology of the world system, Maria Celia Coelho's examination of the social and environmental effect of the rail line from Carajás through the Amazon jungles to the coast, and Maurilio de Abreu Monteiro's analysis of the material and energetic flows of the various minerals enterprises in the Amazon have all built on and elaborated these ideas.

Collaborative work with Denis O'Hearn comparing strategies of importing and exporting nations in the world aluminum industry at different moments of world-system history(Bunker and O'Hearn, 1992; Barham, Bunker, and O'Hearn, 1994) and discussing his work on the world systemic effects of technological innovation in the cotton textile industry helped me move from local to global perspectives. I benefitted enormously from lengthy discussions with Ty Priest during his research and analysis of U.S. strategies to acquire manganese. I learned a great deal as well from; Paul Ciccantell's comparison of Venezuelan and Brazilian responses to the Japanese strategies to transform world aluminum markets; Paul Gellert's analysis of the interactions between the rivers and ports of East Kalimantan, the collusion of Indonesian capital and the Indonesian state to control and profit from the extraction, transformation and sale of *Diptherocarp*, and Japanese capital, consumption, and state policy; and Jonathan Leitner's examination of struggles between Britain and the U.S., and

---

conjunctural (Paige, 2000) analysis in ways that overcome Paige's objections to the social scientific search for regularity and generality of explanation.

then between interests in different U.S. regions to control world and American copper markets. These case studies greatly extend the reach and the specificity of this model, while at the same time demonstrating concretely and practically that attention to space and matter refines the empirical and theoretical bases not just of enviromental history and sociology, but of a broad range of other socially, political, and economically relevant fields of research.

As Paul Ciccantell and I worked through these issues, we noticed again the crucial role of technical economies of scale and huge increases in capital sunk in transport infrastructure, in reducing the cost of moving raw materials through space and so expanding the space across which cheap, bulky, raw materials could economically be moved. Making sense of the ways that the Japanese restructured and globalized raw materials markets, we had to look at earlier technological revolutions that caused huge, step-wise jumps in economies of scale in processing the bulkiest, cheapest raw materials and in their transport.

As we compared the access strategies and transport technologies of Amsterdam, Great Britain, the U.S., and Japan, we saw how technological innovations directly influenced by material features had led to new economies of scale in those industries that consumed the greatest volume of raw materials, and how these scale increases had accelerated depletion of the most proximate sources and therefore drove the search for the most voluminously consumed raw materials across ever greater spaces. Economies of scale thus created their own contradiction in the rising cost of distance across space; the reiterated solutions to this contradiction could only be acheived through even greater economies of scale in transport, which then drove further scale increases in consumption of raw materials, reiterating the contradiction anew.[14] The secular repetition of this cycle, each time expanded, suggests a model of reiterated scale solutions—with their attendant spatial fixes—as a mechanism for the secular movement of the world system toward globalization.

These scale economies in raw materials transport and transformation have preceded each of the expansions of commercial space that Arrighi (1994) identifies as components of each transition between systemic cycles of accumulation. Arrighi explains these expansions primarily as the combined response of states and finance to overaccumulation of capital in the trade dominant nation. In this regard, he follows David Harvey's (1983) explanation of the "spatial fix" or the geographic expansion of capital as the solution to the overaccumulation and consequent devaluation of capital that emerge from the "internal dialectic of capital".

14. See Haydu(1998) for a model of reiterated solutions.

Analysis of the processes that have linked each of the Amazon's extractive economies to the changing demands of the world economy drives us to elaborate another affirmation that Harvey adopts from Marx; that technology mediates between society and nature. In other words, we attempt to integrate the spatial and material history of world raw materials markets and transport with the financial and political dynamics of world capital. Technology and infrastructure can mold space and matter only with the direct intervention of politics and finance.

The history of the Amazon shows that technology—both in transport and in production—is cumulatively expansive in its scale, in its power, and in its cost. Comparative analysis of the rubber, iron, and aluminum economies in the Amazon suggests that core firms and states devise, promote, finance and implement these technologies as part of their strategies to achieve trade dominance. To achieve the competitive advantages and economies that trade dominance requires, these technologies must conform to the material characteristics and locations in space of the raw materials whose transportation and transformation they cheapen and expand.

In this sense, the materio-spatial features of extractive peripheries set boundaries on the core nation's technical innovations. This materio-spatial determinancy of the periphery is negated by the political and economic subordination of the periphery to these new economies of scale. Each extractive episode involved the transport of greater volumes of goods—from spices to turtle oil to fine woods to rubber to iron ore—more cheaply over greater distances. The increasingly costly investments in local transport infrastructure have devolved more and more upon the local economy. Carajás, dependent on the global transport of an ore whose huge consumption in the world market rests on its very low value to volume, is but the latest, and most dramatic, example of how transport technologies devised to solve the tension between scale and space, promote globablization by cheapening ton/miles at the suppliers' expense. This cheapening is essential to competitive capital's procurement of raw materials over an ever broader part of the globe.

To understand the spatio-material and technological expansions and intensifications underlying globalization, we must simultaneously specify the geographically differentiated materialization of space into the topographic, hydrologic, geologic, and climatologic attributes of different locations as these determine the quality and character of the raw materials through which they participate in the world economy. The essential obverse of materialization of space lies in the spatial differentiation of matter as manifest in the location of different use values.

Both the materialization of space and the spatial location of matter impinge on human economic activity according to the technologies of extraction, production and transport. The specific physical and chemical properties of Amazonian rubber, for example, made it more amenable to the technical manipulations of the industrial technologies that dominated the mid–19th century world market. The utility and abundance of that spatially particular type of rubber meant that most of the technological innovations to improve and extend the industrial uses of rubber were researched, designed and implemented around the specific chemical and physical properties of Amazonian rubber. Similarly, just as the technologies that drove the mid 19th century expansion and progressive mechanization of iron extraction and smelting were developed in response to and interaction with the physical properties and topographic locations of the huge iron ore deposits around the Great Lakes, the potential profits that motivated the huge investments in Carajás reflected the physical and chemical compatibility of the deposit with the most profitable technologies and the accessibility of the deposits to the most economical forms of transport. In other words, the technologies of transport and transformation of the most voluminously used raw materials have expanded and grown in power in simultaneous interaction with the scale increases in the world economy and with the materio-spatial attributes of specific local sources.

From this perspective, globalization must eventually collide with inexorable natural limits of both space and matter. At the local level, the inequality between extractive and productive economies (Bunker, 1985; Bunker and Ciccantell, 2001), and the unbalanced flow of matter and of energy from the extraction to production which informed my analysis of the developmental and environmental effects of the Amazon's rubber boom and bust (Bunker, 1982), can only become greater as economies of scale approach these natural limits. At the global level, the internal dialectic of capital has driven each systemic cycle of accumulation first to site-specific or local depletion of the technically most accessible raw materials and then to the overaccumulation and devaluation of capital in the dominant economy.

Thus far, each episode of these material and financial dilemmas has been resolved by a spatial fix that has incorporated new types and deposits of raw materials into new technologies and infrastructures of transport. The investments in the transport systems required to incorporate these new sources of material into the world market also provide avenues for the extension of commerce and investment into expanding global markets. As the most voluminously used, lowest value-to-volume raw materials are introduced into global trade, the potential for future crises of resource depletion and capital devaluation increases, while the potential for spatial fixes through discovering large new deposits in more distant places, decreases. is eliminated. The next great crisis of capital may

result as from spatio-material constraints rather than from financial responses to overaccumulation and devaluation. The question then will be whether the states, firms and sectors—whose strategic collaborations to achieve national dominance of world trade by investing in new scale economies have led to this crisis—will be able to invent new forms of collaboration that do not require material intensification or spatial expansion.

REFERENCES

Albion, R. (1926). *Forests and Sea Power: The Timber Problem of the Royal Navy, 1652–1862*. Cambridge: Harvard University Press.

Alden, Dauril (1976). "The Significance of Cacao Production in the Amazon Region during the Late Colonial Period: An Essay in Comparative Economic History," *Proceedings of the American Philosophical Society*. 120:103–35.

Arrighi, Giovanni (1994). *The Long Twentieth Century: Money, Power, and the Origins of Our Times*. London: Verso.

Barham, Bradford, Stephen Bunker and Denis O'Hearn (1994). "Raw Materials Industries in Resource Rich Regions," Pp. 3–38 in B. Barham, S. Bunker and D. O'Hearn (eds.). *States, Firms, and Raw Materials: The World Economy and Ecology of Aluminum*. Madison: University of Wisconsin Press.

Brockway, Lucile, 1979. *Science and Colonial Expansion: The Role of the British Botanical Gardens*. New York: Academic Press.

Bosson, Rex and Benson Varon (1977). *The Mining Industry and the Developing Countries*. Oxford: Oxford University Press.

Bunker, Stephen G. (1985). *Underdeveloping the Amazon: Extraction, Unequal Exchange, and the Failure of the Modern State*. Urbana, IL: University of Illinois Press.

Bunker, Stephen G. (1986). "On Values in Modes and Models: Reply to Volk," *American Journal of Sociology*. 91 (6):1437–44.

Bunker, Stephen G. (1992). "Natural Resource Extraction and Power Differentials in a Global Economy," Pp. 61–84 in S. Ortiz and S. Lees (eds.) *Understanding Economic Progress*. University Press of America.

Bunker, Stephen G. (1994a). "The Political Economy of Raw Materials Extraction and Trade," Pp. 437–450 in R. Socolow, C. Andrews, F. Berkhout, and V. Thomas (eds.) *Industrial Ecology and Global Change*. Cambridge: Cambridge University Press.

Bunker, Stephen G. (1994b). "Flimsy Joint Ventures in Fragile Environments," Pp. 261–296 in B. Barham, S. Bunker, and D. O'Hearn. *States, Firms, and Raw Materials: The World Economy and Ecology of Aluminum*. Madison, WI: University of Wisconsin Press.

Bunker, Stephen G. (1996). "Raw Material and the Global Economy: Oversights and Distortions in Industrial Ecology," *Society and Natural Resources*. 9:419–29

Bunker, Stephen G. and Paul Ciccantell. (1994). "The Evolution of the World Aluminum Industry," Pp. 39–62 in B. Barham, S.Bunker and D. O'Hearn (eds.). *States, Firms, and Raw Materials: The World Economy and Ecology of Aluminum*. Madison, WI: University of Wisconsin Press.

Bunker, Stephen G. and Paul Ciccantell. (1995). "Restructuring Space, Time, and Competitive Advantage in the World-Economy: Japan and Raw Materials Transport after World War II," in D. Smith and J. Borocz (eds.) 1995. *A New World Order? Global Transformations in the Late Twentieth Century*. Westport, Connecticut: Greenwood Press.

Bunker, Stephen G. and Paul Ciccantell (2000). "Generative Sectors and the New Historical Materialism: Development and Underdevelopment in the World and National Economics," Paper presented at the ASA meetings, Washington, DC.

Bunker, Stephen G. and Paul Ciccantell (2001). "International Inequality in the Age of Globalization. Japanese Economic Ascent and the Restructuring of the Capitalist World-Economy," Paper presented at the ISA meetings, Chicago.

Bunker, Stephen G. and Denis O'Hearn (1992). "Strategies of Economic Ascendants for Access to Raw Materials: A Comparison of the U.S. and Japan," Pp. 83–102 in Ravi Palat (ed.) Pacific Asia and the Future of the World System. Westport, CT: Greenwood Press.

Chase-Dunn, Christopher, Yukio Kawano, and Benjamin Brewer, 2000. "Trade Globalization since 1795: Waves of Integration in the World-System," *American Sociological Review*. 65: 77–95

Ciccantell, Paul (2001). "NAFTA and the Reconstruction of U.S. Hegemony: The Raw Materials Foundations of Economic Competitiveness," *Canadian Journal of Sociology*: 26:3.

Ciccantell, Paul (1994). "Raw Materials, States and Firms in the Capitalist World Economy: Aluminum and Hydroelectricity in Brazil and Venezuela," Ph.D. dissertation, University of Wisconsin-Madison.

Ciccantell, Paul and Stephen G. Bunker (1997). *Space and Transport in the World System*. Westport, CT: Greenwood Press.

Ciccantell, Paul and Stephen G. Bunker (1999). "Economic Ascent and the Global Environment: World-Systems Theory and the New Historical Materialism," in Walter Goldfrank et al. (eds.). *Ecology and World-Systems Theory*. Westport, CT: Greenwood Press.

Ciccantell, Paul and Stephen G. Bunker (2002). "International Inequality in the Age of Globalization: Japanese Economic Ascent and the Restructuring of the Capitalist World Economy," *Journal of World-Systems Research*, 8(1):62-98. http://jwsr.ucr.edu/

Coelho, Maria Célia Nunes Coelho (2000). "Política e Gestão Ambiental (des) Integrada dos Recursos Minerais na Amazônia Oriental," Pp. 117–170 in M.C. Nunes Coelho, L. Simonian, and Norbert Fenzel, (eds.), *Estado e Políticas Públicas na Amazônia: Gestão de Recursos Naturais*. Belém: Editora Cejup

Fittkau, Ernst Josef (1973). "Crocodiles and the Nutrient Metabolism of Amazonian Water," *Amazoniana* IV 1, 103–133.

Gellert, Paul (1997). "The Limits of Capacity: The Political Economy and Econology of the Indonesian Timber Industry, 1967–1995," Ph.D. dissertation, Sociology, University of Wisconsin-Madison

Haydu, Jeffrey (1998). "Making Use of the Past," *American Journal of Sociology*. 104(2): 339–71

Harvey, David (1983). *Limits to Capital*. Oxford: Blackwell

Hecht, Susanna B. (1985). "Environment, Development, and Politics: Capital Accumulation and the Livestock Sector in Eastern Amazonia." *World Development*: 13(6):663–84

Hemming, John (1978). *Red Gold: The Conquest of the Brazilian Indians*. Cambridge: Harvard University Press.

Hugill, Peter (1994). *World Trade Since 1431: Geography, Technology, and Capitalism*. Baltimore, MD: Johns Hopkins University Press.

Innis, Harold A. (1933). *Problems of Staple Production in Canada*. Toronto: Ryerson Press

Innis, Harold A. (1956). *Essays in Canadian Economic History*. Toronto: University of Toronto Press.

Jörnmark, Jan (1993). *Coal and Steel in Western Europe, 1945–1993: Innovative Change and Institutional Adaptation*. Göteborg: University of Göteborg

Katzman, Martin T. (1987). "Review Article: Ecology, Natural Resources, and Economic Growth: Underdeveloping the Amazon," *Economic Development and Cultural Change*. 35(2):425–437.

Lathrap, Donald W. (1977). "Our Father the Cayman, Our Mother the Gourd: Spinden Revisited, or a Unitary Model for the Emergence of Agriculture in the New World," Pp. 713–31 in C.A. Reed, (ed), *Origins of Agriculture*. Paris: Mouton Publishers.

Lefebvre, H. (1991). *The Production of Space*. Oxford: Blackwell

Leitner, Jonathan (1998). "Upper Michigan's Copper Country and the Political Ecology of Copper, 1840's–1930's," Ph.D. dissertation, Sociology, University of Wisconsin-Madison.

Leitner, Jonathan (forthcoming) "Log Transport, Regional Capitalist Conflict, and Corporate Formation in a North American Timber Economy: Wisconsin's Chippewa Basin, 1860–1900," *Review*.

Mandel, Ernest (1975). *Late Capitalism*. London: New Left Review Editions

Marx, Karl (1967). *Capital: A Critique of Political Economy*, Volume III. New York: International Publishers.

Merchant, Carolyn (1983). *The Death of Nature: Women, Ecology, and the Scientific Revolution*. San Francisco: Harper and Row.

Monteiro, Maurillio de Abreu (2001). "Mineraçâo Metallurgica na Amazônia," Ph.D. dissertation, Nucleo de Altos Estudos Amazonico, UFPa, Belém: Brazil

Murphy, R. Taggart (1996). *The Weight of the Yen*. New York: Norton and Co.

Nimuendaju, Curt (1954). "The Tapajó," *Kroeber Anthropological Society Papers*. 6:1–12.

North, Douglass C. (1958). "Ocean Freight Rates and Economic Development, 1750-1913," *Journal of Economic History*.18:538–555.

North, Douglass (1966). *Growth and Welfare in the American Past: A New Economic History*. Englewood Cliffs, NJ: Prentice-Hall.
O'Hearn, Denis (1994). "Innovation and the World-System: British Subjugation of the Irish Cotton Industry, 1780–1830," *American Journal of Sociology* 100(3):587–621.
O'Rourke, Kevin H.O. and Jeffrey Williamson (1999). *Globalization and History; The Evolution of a Nineteenth-Century Atlantic Economy*. Cambridge, MA: MIT Press.
Paige, Jeffery (1999). "Conjuncture, Comparison, and Conditional Theory in Macrosociological Inquiry," *American Journal of Sociology*. 105(3):781–800.
Palmatary, Helen Constance (1960). *The Archaeology of the Lower Tapajós Valley, Brazil*. Philadelphia: Transactions of the American Philosophical Society.
Priest, R. Tyler (1996). "Strategies of Access: Manganese Ore and U.S. Relations with Brazil, 1894–1953". Ph.D. dissertation, History, University of Wisconsin, Madison
Roberts, Timmons (1995). "Trickling Down and Scrambling Up: The Informal Sector, Food Provisioning, and Local Benefits of the Carajás Mining Growth Pole in the Brazilian Amazon." *World Development*. 23(3):385–400.
Robinson, William I. (2001). "Transnational Processes, Development Studies, and Changing Social Hierarchies in the World System: A Central American Case Study." Paper presented at ISA meetings, Chicago
Santos, Roberto (1968). "O Equilibrio da firma 'aviadora' e a significação econômico-institucional do "aviamento". *Pará Desenvolvimento*, 3. Belém: IDESP.
Santos, Roberto (1980). *Historia Economica da Amazonia (1800–1920)*. Sao Paulo: T.A. Queiroz.
Sioli, Harold (1975). "Tropical River: The Amazon," Pp. 461–488 in B. A. Whitton (ed.), *River Ecology*. Oxford: Blackwell Scientific Publications
Sklair, Leslie (2000). *The Transnational Capitalist Class*. Oxford: Blackwell Publishers.
Smith, Neil (1984). *Uneven Development*. Oxford: Blackwell.
Smith, Nigel (1974). "Destructive Exploitation of the South American River Turtle," *Association of Pacific Coast Geographers*. 36:85–101.
Smith, Nigel (1980–81). "Caimans, Capybaras, Otters, Manatees, and Man in Amazonia." *Biological Conservation*. 19:177–187.
Soja, E. (1989). *Postmodern Geographies*. New York: Verso
Sweet, David (1974). "A Rich Realm of Nature Destroyed." Ph.D. dissertation, History, University of Wisconsin-Madison
Tilly, Charles (1995). "To Explain Political Processes," *American Journal of Sociology*. 6: 1594–1610.
Tomich, Dale (2000). "The World after the World System," Paper presented at the Social Science History Association, Pittsburgh.
Volk, Robert U. (1986). "Comment on Bunker," *American Journal of Sociology*. 91(6): 1431–37.
Weinstein, Barbara (1983). *The Amazon Rubber Boom, 1850–1920*. Stanford, CA: Stanford University Press.
Wittfogel, Karl. 1985 [1929]. "Geopolitics, Geographical Materialism, and Marxism," *Antipode* 17(1):21–72.