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Technological Determination and Determinism: Industrial Growth and Location

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☐ WITH THE BREAKDOWN of neoclassical hegemony in location theory, interest has shifted from the realm of exchange to the realm of production and, thence, to technology. This has dovetailed with a revival of interest in Schumpeter's ideas about technical innovation as the prime mover of economic growth and business cycles. Meanwhile, technology has come to be viewed by the public as the key to the magic kingdom of regional development and national competitiveness. As substantial technological changes and regional shifts are unquestionably in progress, it is salutory that economic geographers are looking seriously into the subject of technology in the spatial patterning of economic growth (for a review, see Malecki, 1983). This process has only begun. It is not surprising, therefore, that various kinds of technolgical determinism have found their way into the regional debate, such as the notion that high tech industries have a unique locational pattern, that R&D centers are crucial to local growth because of their innovative function, or that the product cycle dooms older industrial regions to imminent stagnation.

I wish to drive a wedge into the cracks in some common ideas about technology and location in order to open up further room for

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debate. I do not do this as an antagonist of the idea of technological determination, pushing a putative "Marxist" line about the monocausal force of social relations. Quite the contrary, I see technology as an essential structuring factor in industrial development and location. Nonetheless, it is necessary to frame the limits of technological determination. Technology must be set against other, equally fundamental aspects of the capitalist economy and capitalist growth, particularly capital-capital (competitive) and capital-labor (class) relations. The collision—or, rather, tension—between the relations and forces of production shapes the course of industrial development. Second, historical outcomes are not mere results of impersonal forces, like the ricocheting of billiard balls. Therefore, determinism must be replaced by a structural-realist view of cause and effect that comprehends the gap between underlying causes and actual outcomes, given the infinite possibility of intervening contingencies, which in history (unlike in a laboratory) never can be controlled. To this must be added the necessary intervention of human consciousness and human agency, of choice and struggle. These render all social history an open system, in which results never may be read off from technology or any other deterministic force, no matter how tight the bonds of social structure may appear (Giddens, 1979; Sayer, 1982a; Walker, 1985).

The first part of this chapter dissects industry cross-sectionally, looking at four technological dimensions of production: product, process, linkage, and division of labor.[1] It lays a groundwork for the rest of the discussion in the specificity of industries along these several dimensions. The second part looks at the patterns of technical change and how they further distinguish the developmental paths of industries and their rhythms of growth. The third section uses these insights about technical structuring of industry and growth to critique deterministic models of the technical imperative in the location of industry and regional development patterns, in terms of the spatial division of labor; spatial linkages and agglomeration; technical change and relocation; and innovation and regional growth.

TECHNOLOGY AND THE ANATOMY OF PRODUCTION

Technology casts industries in different molds and sets them down different paths of development. Nontechnological factors augment these differences. Of course, certain technical and social factors lend commonality to the fates of industries—most obviously, their organ-

ization under the rules of a capitalist mode of production. But that does not justify the reductionist view of technique as the outcome of either price ratios (neoclassical theory)[2] or class struggle (labor control theory). The physical character of the technological problem of transforming nature to a usable form has an irreducible effect on the shape of production. I consider four aspects of technology here: product, process, division of labor, and linkages among products and processes.[3]

THE PRODUCT AND ITS USES

Conventional economics focuses on one side of commodities, exchange value. By the trick of marginal substitution all differences of use-value are erased at the moment of consumer choice. But the physical, technical shape of use-values matters. The uses of the bicycle and the banana cannot be interchanged. Neither are the bicycle and the automobile adequate substitutes, nor the trolley and the motorcar. The physical character of each makes for a distinct experience of movement, to which people are not indifferent. Indeed, the introduction of each opened up a whole new range of "needs" among the public (Walker, 1981a). One may apply Rosenberg's (1982) term "learning by using" to this process. Products thus literally embody use-value, rather than simply satisfying preexisting uses dreamed up by the brain of the consumer.[4] Alas, the problem of use-values in consumption has been little theorized (see, however, Lebowitz, 1977/1978; Harvey, 1982; Gintis, 1972).

On the supply side, products as physical, technical entities do not emerge from a void. They evolve from preexisting products and processes, often as the unanticipated results of solving technical problems in the functioning of the product, production of a product, or the effort to meet an unsatisfied need. The transistor was meant to be a better vacuum tube, not the precursor of the microprocessor. The physical properties of products lend a particular thrust to the direction of product evolution, regardless of economic and social forces. "Market demand" is not an adequate explanation for the course of technical development (Rosenberg, 1982: 193-245).

Thanks to the inherent properties of products, markets and product evolution follow different paths for different industries, or what Nelson and Winter (1977) call "natural trajectories."

But technical determination bumps into the social practices of consumption and production. Central to consumption is the relation between the preexisting ideas and practices of consumers and the changing use-values thrown onto the market. Industrialists engage in a war of maneuver with one another and the consuming public over the very definition of wants, in order that their products might be the ones chosen as best satisfying such desires (Ewen, 1976). The "sales effort" is not mere ideological manipulation, however. Consumer practice is shaped through the introduction, use, and promotion of products.

Value and class relations enter into the calculus, as well, in that the cost of products and the distribution of income limit what patterns of use are feasible, whose needs may be filled. Demand must be *effective* demand (Harvey, 1982).

The clearing of product markets rests on a balancing act in which not only value and use-value but use and use-value must be reconciled. The market achieves this end to a remarkable degree, but only through considerable bending of prices, product modification, and forcing of wants; periodically, it fails and the result is glut and forced devaluation of commodity-capital. If products were butter to be squeezed into new shapes at will, much of the problem could be avoided; but they have technical rigidities in consumption and production, the same as capital equipment (Harcourt, 1972). **In short, the ordinary product cycle view of product maturation and market saturation (Burns, 1934; Kuznets, 1930; Vernon, 1960, 1966; Hirsch, 1967) must be replaced by a more supple one, less based on analogy with natural aging.**

The relation of products to industries must also be reconsidered. Industries are taken as unproblematic in most economic and geographic literature. A first-pass definition of industry is along the lines of discrete outputs. Yet there is no commonly agreed on way of handling joint products and multiple product lines. The Bureau of the Census's Standard Industrial Codes (SICs) are based on rule of thumb and cannot be strictly compared across any one level; in some cases, a three-digit code well defines an industry, in others it is necessary to go to the five- or even six-digit level (Shepherd, 1970: 104). In other words, some product groups cluster into broadly defined industries, while in other cases important differences persist to a high level of disaggregation. Indeed, some of the unevenness of firm size and behavior within industries, which is commonly attributed to organizational strategies, is actually based on the production of slightly different products (e.g., customized versus standardized microprocessors). Worse yet is the problem of technical change in products: When is it sufficient to define a "new" product and/or a "new" industry? This remains an open question on which there is little theoretical guidance.

COMMODITY CIRCULATION, OR INTERINDUSTRY LINKAGES

It will not do to treat all products as destined for final consumption, however. Roughly 60% of industrial outputs are inputs to other industries. Such "productive consumption" raises some distinctive issues. Principally, it has a stronger technological dimension than personal consumption. Inputs enter into production in patterns largely set by techniques in place, and normally there are only a handful of available techniques for arriving at the same product (Gold, 1979; Rosegger, 1979; for reviews, see Hunt and Schwartz, 1972; Harcourt, 1972). A second basis for differentiating industries, then, is by their marked variations in input-output patterns.

At the same time, industries are linked together by commodity circulation, which flows down pathways set, in large part, by technological considerations. An obvious example is the automobile nexus that includes large parts of the oil, steel, rubber, and glass industries. These clusters are of two kinds, component-assembly production systems (autos, computers) and serial processing production systems (oil refining, petrochemical feedstocks, plastic fabricators). Similarly, technical linkages are pathways down which the impulses of innovation travel, although the ultimate connections of any change are difficult to pin down (Gold, 1979).

A special sort of clustering is given by industries sharing similar production techniques, involving a common technological base and common suppliers of machinery. In such cases, innovations in products serving as inputs have greater impact on productivity than process innovations spawned within the industry itself (Rosenberg, 1976; 141-150). A small number of industries producing capital goods using a basic technology may be responsible for most of the technical change throughout a range of industry. The classic case is the metal-working industry's reliance on machine-tool technology and producers (Rosenberg, 1976: 9-31). Another is the early textile industry-machine producers nexus (Hekman, 1980a). Today the impact of electronics technology is being felt across a wide spectrum of industries to which electronic devices are being supplied (de Bresson and Townsend, 1978).[5] One should be alert to how little we yet know about "technology systems"—as indicated by the definitional vagueness of even such astute observers as Freeman et al. (1982).

Despite the force of technology in fixing interindustry linkages, and of linkages on the shape of technical change, they must be set in an economic context. At the simplest this means recognizing that

some degree of substitution is possible and that price and profit signals do call forth technical changes over time. At the micro level there is a continual jostling of technical and economic considerations in the strategy of the firm (Rosenberg, 1976, 1982; David, 1975; Gold, 1976, 1979). At the macro level—which is the composite but not the sum of the micro—price structure, technology, and income distribution (rate of surplus value) are interdependent; no one can determine the others (Hunt and Schwartz, 1972; Gold, 1976; Storper, this volume). Indeed, what is significant in terms of the dynamics of capitalism is the ability of the system to mesh these conflicting systems over time in such a way as to avoid sectoral imbalances and the outbreak of crisis (Harvey, 1982).

THE DIVISION OF LABOR

I have so far treated industries as if they consisted of a clear-cut product and self-evident production units. Once the idea of linked production systems is introduced, however, it opens up thorny questions concerning the division of labor. The division of labor must be given its due as a distinct field of technological determination, change, and choice.

All production processes consist of many parts. These may be gathered under one factory roof or split between several workplaces. Technical considerations often dictate which makes the most sense; for example, it makes sense to keep work close together if parts can move from one work station to another by conveyor, or if there is a central power source linked to the machinery by belts. Conversely, it may make sense to separate work stations where electric motors are used or "flexible" automation systems are in place. But there is also an element of indeterminancy and choice involved in the organization of complex production, meaning that it is not possible to determine from technology alone where the detail division of labor (within the work unit) will leave off and the social division of labor (between work units) will begin, and which will be embraced by a single "industry" or firm. Our first- and second-cut definitions of industries will not suffice, therefore, because "products" and "linkages" vary by where one draws the line around production. Textile machinery making was part of cloth production until it spun off as a separate industry; and locomotives were part of the latter until they, too, split off. Should steel be produced as part of automobile production, as was done by Ford at River Rouge, or as a separate industry? Should parts move by hand truck or interstate trucking? It will not do to say that the market will decide which is cheapest; what determines cost structures? And it is not merely a cost issue, because labor militancy often provokes capitalists to divide and scatter their workforces, and even to operate redundant plants. Volumes have been written on industrial organization, but we still do not have a theory about why integration proceeds readily in certain industries, certain firms, but not in others (Caves, 1980; Scherer, 1970: chap. 4).

As Rosenberg (1982: 76) notes, "it might be [that] technology flows have radically reshaped industrial boundary lines, and that we still talk of 'interindustry' flows because we are working with an outmoded concept of an industry." Hence, it is better to speak of "production systems" in many cases, as noted above. But it can matter substantially how circulation is organized: A production system embraced by a single corporation is different from several firms linked by the market; a subcontracting system, involving both big firm domination and a special kind of marketing arrangement, is different yet (Murray, 1983). Allen Scott calls this the problem of "integration-disintegration" and focuses attention on economies of "scope"—as distinguished from economies of scale—in production (Scott, 1984; compare NRPB, 1943). But the issue is far from adequately understood.[6]

The problems introduced by the division of labor become even more complex when we include the "indirect labor" components of production systems, such as process engineering, product development, repair, and management (Walker, 1985b). Some technological structuring is discernible, such as the need for long-lived machinery or consumer durables to be repaired or the role of R&D in industries with rapid product proliferation, such as microelectronics. But the economic side of choices about, say, whether to include accounting within U.S. Steel or contract it out, or to commit resources to product differentiation and advertising rather than real product innovation through research, is substantial. A fourth-cut definition of industry might turn on the amount of labor devoted to activities and occupations of an indirect nature across product sectors; this is the strategy chosen by Glasmeier (this volume) to define high tech industry. But it, too, is beset with ambiguities, such as whether technical workers are involved in product development, process change, or marketing. A rather different classification, which cuts across commodity sectors, has arisen to deal with the rise of indirect labor in distinct workplaces, as when one speaks of "the office industry."

THE PRODUCTION PROCESS

Having surveyed some ground often passed over in treatments of technology in industry, we can now take up the production process inside each workplace. All production involves human labor and, as Marx (1967) argues, every labor process has two sides: the production of use-values and the generation of value and surplus-value. The latter is the raison d'etre of capitalism and production would not be undertaken without it. Marx makes a powerful case for the devastating effect of the search for surplus-value on the worker, as well as for the way it drives capitalists to raise the productivity of labor.

Marx's analysis of the labor process still stands as the best treatment of the subject. He does not make the mistake of equating technology with machines, although he understands that "modern industry" revolves around "machinofacture." Instead, he treats three aspects of the application of labor: cooperation, division of labor, and mechanization. Technical change centers on the worker creatively wielding a tool to transform materials into a useful product. They key to the industrial revolution, therefore, is not steam power, but successfully capturing the unique capabilities of human activity—the hand, the eye, the creative mind—in the workings of the machinery.[7] The preconditions for this achievement are cooperation (bringing together many workers) and the detail division of labor (breaking down complex processes into simpler ones and rationalizing them according to mechanical principles). As Freeman et al. (1982: 70) observe, the reorganization of production is as important as the application of technique. The results of this process are, however, the reduction of the former craftworker to a detail worker and ultimately a machine-tender. The process of deskilling has been much in vogue since the effort of Braverman to apply Marx's analysis to the twentieth century.[8]

Nonetheless, Marx's treatment—or, at least, the common understanding of it—needs to be amended in several ways. First, while the tendency to deskill labor is a profound one that runs across all labor processes, the effects of division of labor and mechanization are not uniformly adverse to technical skill: They may lead to reskilling through the command of more specialized tasks (including whole new branches of labor, such as R&D) or the oversight of whole machine systems (Storper, 1982).[9] And, of course, new products and labor processes are constantly being created as the old evolve.

Second, one cannot look at production only as a labor process. It is also a materials-transformation process. The failure to distinguish between the two aspects of the matter has led to no end of confusion. As a labor process, production has common features that span all industries, all workplaces. As the transformation of specific materials into specific products, within the bounds of physical laws, it is characterized chiefly by uniqueness and diversity. So are the concrete tasks and skills of the workers in each industry; as Sahal (1981: 59) observes, "technical know-how is largely product and plant specific" and is not readily transferable to other industries or places.[10] The distinction between materials-transformation and labor process accounts for the gap in the literature between the "choice of techniques" debate (for reviews, see David, 1975; Uselding, 1974; Kennedy and Thirlwall, 1972) and "labor process" studies (for review see Elger, 1979). If we assume that the choice is a simple one between more and less capital-intensive methods, and that these represent movements along the vector of mechanization, then the two sides collapse to one. On the contrary, there are several vectors of mechanization (or greater input productivity) possible for an industry. The choice of technique involves jumps both between vectors and along vectors that are themselves discontinuous.[11] In any case, the neoclassical vision of smooth substitution of factors along a tidy production function does not hold (Rosenberg, 1976: 61-84; Hunt and Schwartz, 1972; Harcourt, 1972; Gold, 1979).

The material differences among production processes, like those among products, set industries down very different paths of development. Innovations in processing, handling, and monitoring have a materials component that has a logic of its own (as, for example, how to make a part stronger, more malleable, or accepting of more electrical circuits). Technical considerations also establish the possibilities and set the limits on the course of division and mechanization of the labor process. The tendency to revolutionize production runs into the concrete technological diversity of the products to be made; the problems inherent in automating garment and petrochemical production are worlds apart. Some industries never advance much beyond the craft stage: Ships, one of the oldest products, are still made by small-batch process; scientific instruments may be "high tech," but their production still is labor-intensive (Oakey, 1983).[12] Finally, material considerations may impel as well as impede mechanization: For example, quality control in microchip production demands greater mechanization (it might well require more labor in another industry, however). One cannot explain the radical differences among industries in growth of productivity (Kendrick, 1973) except by

reference to different technical potentials inherent in specific products and material processes (Nelson and Winter, 1977; Sahal, 1981).

The disjunction between the two sides of production also addresses the riddle of bias in process change (see, again, David, 1975; Uselding, 1974; Kennedy & Thirlwall, 1972). From the materials side, technical change will be neutral as there is no incentive to save on one input more than another (Salter, 1966). From the labor side, however, mechanization always involves labor-saving (greater output to labor ratio).[13]

A third consideration is to recognize the irreducible human element in all labor processes, regardless of technological proficiency and the drive for surplus-value. While people may be constructed along common lines, lending a homogeneity to all labor processes, labor can never be entirely rationalized and given over to machines. The creative human element remains, if only in seeing that the machines perform as programmed (Aronowitz, 1978; Cressy & MacInnes, 1980; Manwaring & Wood, 1984). Every labor process demands special skills that can only be learned through practice on the job. It also requires that workers mobilize their labor and exercise their creativity. Production requires not merely choosing the right mix of "labor inputs" to fit technically-given tasks, but hiring and molding, through the experience of work and managerial control systems, the kind of labor force that will get the job done and done well. This is no mean trick. It only happens through a process of class-structured maneuver and conflict that includes group socialization, the application of managerial power, and various forms of worker resistance within the context of the job to be done, the leverage given workers by their skills, labor market conditions, product market conditions, and the like (Storper & Walker, 1984). Because there is no unique outcome to the social order of the workplace, labor demand cannot be read off from production technique and organization. The concepts of strictly technically determined "skill" levels and "marginal products" of labor are untenable.

The variable condition of the employment relation augments the differences among industries. Furthermore, as has been frequently observed, the state of labor relations affects the course of technical change. Machinery has often been used to break the hold of skilled and/or unionized workers; conversely, militant workers may prevent the introduction of new techniques or docile and low-paid workers blunt the capitalist's drive for technical change (Marx, 1967; Rosenberg, 1976: 117-120). Thus, the path down which technology travels and the rate of movement depend on the social relations of employment.[14] The intervention of class conflict and maneuver into process of technical change add a further element of uncertainty and disjointedness to the flow of innovation, beyond that which comes from purely technical considerations of the imperfect meshing of technology and market.

Fourth, the course of process evolution, like that of product development and the division of labor, is affected by (output) market conditions. A product may lend itself physically to mass machine production, but will not be so made if no market exists. For example, U.S. semiconductor manufacturers have long held that shifting market conditions, owing to rapid product innovation, do not justify heavy investment in mechanized chip production. On the other hand, falling unit price (value) may create a mass market where none existed before, as has also happened in semiconductors. In fact, supply side changes in technique (and other variables) are constantly altering the cost structure of production, altering the shape of effective demand. In short, demand does not just call forth supply; supply can also generate its own demand. The dynamic interaction between the two is the place to focus attention, instead of the fruitless quest for linear cause and effect from one putatively independent variable to another (Rosenberg, 1982: 231-232).

Finally, I should touch once more on the troublesome problem of defining industries. There is a wide range of technologies in use in every industry. Some of the differences are due to mixing of different products (overaggregation), some to the age of fixed capital (a vintage problem along similar lines of development), some to the complex division of labor in most sectors (mixing direct and indirect labor processes). Nonetheless, firms within a single industry are able to set themselves on different courses, some of which alter the course of the industry. Averaging across such differences as if the development path of an industry were a certainty, along which there are leaders and laggards, hides the role of human agency in the process of technical change.

In sum, a multitude of possibilities emerge from the interaction among technological (product, process, and division of labor), use-value, value, and class relations. Therein lies the wellspring of divergence between industries—and of the problems of industry definition. Despite the technical sources of industry differences, therefore, it will not do to call their paths of development "natural trajectories," for the social element looms so large in the history of every industry, from worker resistance to consumer acceptance. It is worse yet to jump from natural trajectories to organic analogies of growth, as in the product cycle. The next section takes up the

question of the technological impetus to industrial development and the effect of technology on the pattern of industrial growth over time.

TECHNOLOGY AND INDUSTRIAL DEVELOPMENT OVER TIME

THE PROCESS OF TECHNICAL INNOVATION

We must first dispose of the idea that industrial growth is triggered by major technical innovations—the big bang theory. One finds this idea throughout the literature on innovation diffusion and the product cycle. It rests on fundamental misconceptions as to the way technological change proceeds and how it fits into the wider regime of accumulation.

Some principles of technical change can be enumerated that belie the big bang theory, even while strongly supporting the idea of technological determination in the course of technical change. That is, technical change is, to a significant degree, internally generated by work to solve technical problems and internally structured by the nature of the physical products and processes of production.[15]

(1) Technology does not flow from science,[16] as in the linear view of causality embodied in the trilogy "invention-innovation-diffusion." Philosophically, the trilogy rests on an idealized view of knowledge as the product of contemplation rather than practice (labor); ideas appear in the head of the theoretician and are then applied by the manual worker. This is not even true of science, which requires quite a bit of hard work, let alone of knowledge in general (Bhaskar, 1978). Sociologically, it involves a fetishism of science as true knowledge and scientists as priests who function in a different way from ordinary mortals (Sayer, 1981). Industrially, it simply does not square with the evidence.

The history of industrial technology, from the steam engine to the modern airplane, is that it usually runs ahead of scientific understanding of the underlying principles involved (Rosenberg, 1982: 141-159; Sahal, 1981: 30-32). It is not unusual for industrial engineers to develop a solution to a problem for which there is no scientific explanation, and for that to spur scientific research (Rosenberg, 1982: 126). Industrial technology also gives to science most of its instruments of investigation, which are critical to posing questions as well as verifying solutions. Conversely, the performance characteristics of industrial technologies cannot be predicted well by theoretical science (Rosenberg, 1982: 122). This is to be expected;

according to the realist conception, scientific explanation deals chiefly with underlying mechanisms abstracted from intervening contingent causes, and not the complexities of real situations in which the latter are heavily implicated (Bhaskar, 1978; Sayer, 1982a). It is one thing to know how gravity affects the fall of the apple, another to design an apple picker.

Technical innovation derives principally from practical experience with production. Practical problems are encountered, practical solutions are proposed. "Innovation [is] a process of learning by experience." Moreover, "the process of learning tends to be technology specific" (Sahal, 1981: 37). Few operating production processes are based on formal blueprints, especially after long periods of adaptation (see below). As one plant engineer complained: "If we waited until the designs were completed, we would never start building" (quoted in Piore, 1968: 605).

This does not mean that innovation only takes place on the shop floor, that research and design workers may not be a separate group of workers laboring in another corner or even another building, or that industrial engineers do not refer to scientists and scientific journals as they search for solutions (Price and Bass, 1969). Nonetheless, "the gist of science lies in indicating what is *not* possible" (Sahal, 1981: 62). Practical inventions do not, as a rule, flow from scientists and little industrial R&D is basic research. Industrial engineers have to interact with the production line and the marketing office, and good ideas come from ordinary workers all the time (Piore, 1968).[17] Working production processes are rarely captured in formal blueprints (Piore, 1968).

One must also carefully consider the conditions under which scientific principles may be applied to production—e.g., after a degree of rationalization and division of labor (Marx, 1967; Rosenberg, 1982: 39-51). Despite all the attention to R&D in the literature, there is little evidence that R&D effort explains technical change (for reviews, see Mansfield, 1972; Kennedy and Thirlwall, 1972, 44-50; Sherer, 1970). This is partly because so much invention is happenstance and has unanticipated consequences (Jewkes et al., 1959; Peters, 1983). But it is mostly because R&D and rate of innovation are not independent variables; they depend on the nature of the technology: "The inventive performance of an industry is determined mainly by the nature of its technology" (Sahal, 1981: 57; Phillips, 1971). Promising industries have both high levels of R&D and high rates of technical change; hence, R&D is highly concentrated in a handful of industries (Mansfield, 1972).

(2) "Inventions," do not burst, fully formed, upon the industrial stage. Technical change is made up of a stream of small innovations and incremental improvements in products and equipment, not a handful of revolutionary ones. This is to be expected from a process based on practice and tinkering. Technical change is part of a larger process of improving production through experience, which has been dubbed "learning by doing" (David, 1975; and literature cited there). Even the best idea needs a long series of improvements to perform well. Virtually all inventions require years to be adopted initially (a commonly cited figure is 11 years),[18] years more to be adapted widely, and longer to hit their peak performance. All of these lags result from the need to improve or alter a basic product or process for different specific uses (Gold, 1979; Rosenberg, 1976: 71-73). As Gold (1976: 2) observes, "innovations trigger a continuing process of changes. . . . It is through the ensuing complex of interactions that the innovation is 'digested' by means of progressively more far-reaching adaptations and its effects thereby diffused through the system and over time . . . as a result, the distinctive effects of the given innovation become increasingly indistinguishable." Because of the time lag, several innovations are likely to be in the process of digestion at any time. The reach of an innovation will depend on its adaptability to related activities; apparent pathways may be blocked. Both major and minor innovations are clustered unevenly (Sahal, 1981: 59). Such events are unpredictable because of the inevitable dialectic of dull labor and creative breakthroughs, of human effort and the possibilities inherent in a technology (Sahal, 1981: 41; Jewkes et al., 1959; Peters, 1983).

Because learning and innovation are object- and process-specific and build on one another, technical change is "localized"; every technological choice circumscribes the course of further development (David, 1975: 55-91; Sahal, 1981: 199). This adds further force to the idea of restricted industry development paths.

(3) Technology creates its own "compulsive sequences" of problems and solutions (Rosenberg, 1976: 112). This pushes industries even harder down technically structured paths. The basis of such sequences are the technical complementarities between related parts of a single machine, of a unified production process within a factory, or between different sectors of the social division of labor (Marx, 1967; Rosenberg, 1976: 110-117, 201-206; 1982, 56-62, 70-80; Nelson and Winter, 1977; Piore, 1968). An improvement in one area reveals the inadequacies of another, as when miniturization so reduces computers that the conventional TV picture tube becomes a barrier to portability. Or the imbalance may be felt in terms of bottlenecks in the

flow of materials from one process (or industry) to another. There is no reason to expect that such imbalances can ever be eliminated; moreover, correction in a lagging sphere may catapult it ahead of the formerly leading sphere.[19]

Another kind of complementary technical change is that between substitute products or processes. Not only do new techniques not burst full born on the market, old ones often undergo dramatic improvement under the spur of competition or benefit in other ways from the environment created by the new (Rosenberg, 1976: 202-206; Uselding, 1974: 186-188; Mak and Walton, 1978).

Finally, there are pathways of diffusion between linked technologies and industries, by which technical change in one area helps improve a related process or product (see above).[20] Because of its experiential base, however, technology is not a universal bag of tools that can always be transferred easily from one industry or country to another. Diffusion follows pathways of use; it requires improvement and adaptations; and it does not follow an S-curve of growth (Sahal, 1981: 106). By the same token, followers often do better than leaders in innovation because they are not trapped in an environment and experience that restricts a technology of widespread significance to a truncated use.

(4) Despite the incremental nature of technical change, the sum of such changes is not incremental: That is, there are basic design frameworks within which work advances. Oft-cited examples are the steamboat, the tractor, and the DC-3 aircraft. Sahal (1981: 64) calls these frameworks "technological guideposts," Nelson and Winter call them "technological regimes": What they are advocating is a "structural" view of technological systems, in which an underlying pattern lends coherence to many small changes. "Evolutionary changes do not just pile up. They inevitably build up into a system" (Sahal, 1981: 64). This similar to recent theories of how science evolves (Kuhn, 1970; Piaget, 1970; Bhaskar, 1978). It gives further meaning to the idea of technical determination of industry development paths.

Because technical progress is structured by the nature of the product and process, the possibilities for improvement in a basic design can be exhausted in time. There is, therefore, a limited range within which something like the product cycle can take place. Recall, however, that the level of process development (especially mechanization) to which production "matures" depends on the kind of product and market.[21] Nonetheless, technological exhaustion must be balanced against technical breakthroughs.

(5) Given the structured nature of technological change, it is possible to speak of technical breakthroughs. Such breakthroughs, or qualitative shifts to new structures of design, do not ordinarily occur at a pop, but become apparent as a line of development reveals its technical potential. From the individual perspective, the breakthrough may be an act of genius that solves a big problem; more often it is the unanticipated result of solving a smaller problem—"overshooting of the mark is characteristic of exploratory activities . . . the size of the discovery need bear no systematic relationship to the size of the initial stimulus" (Rosenberg, 1976: 115). From a systematic perspective, breakthroughs come in terms of structural change within a sector (e.g., a product design shift) or leaps in technology based on the natural organization of matter (mechanical versus chemical versus electronic technologies), whose effects are widely felt. This is where theoretical "science" may reenter the scene, providing, if not the initial breakthrough, the eventual understanding of natural laws on which a long-run technical flowering is based.

Because of the possibility of breakthroughs, technological exhaustion is relative, not final. "It is characteristic of long-term evolution that barriers to growth frequently prove to be temporary" (Sahal, 1981: 69). Dead-ends can be broken out of by structural transformations from one basic design to another, or achieved, pyramid-style, by combining two prior systems and finding the common principle between them. Sahal (1981: 73) gives the example of combining the tractor with the three-point hitch, and calls the principle "creative symbiosis." The same idea can be found in Marx's analysis of combining machines into automatic machine systems or Piaget's analysis of theoretical advances in the sciences (Marx, 1967; Piaget, 1970).

Technical growth is, therefore, a series of waves, not one long one as predicted by the product cycle.[22] In other words, short-term and long-term change are not the same; one is within a structure, the other involves structural transformation.

(6) One can go beyond particular design systems and apply the same principle of structuration to basic technologies or "technological systems" (Freeman et al., 1982; Nelson and Winter, 1977; Rosenberg, 1976). Such systems are not merely linked by inputs and outputs and complementarities, but by common technological and scientific principles, such as those involved in electrical power or control systems. The exploitation of such principles may carry forward a wide range of industries, even lending definition to whole

eras of industrial progress (e.g., mechanical age, electrical age, electronic age). Industries will differ, however, in their ability to exploit such basic technologies (Nelson and Winter, 1977).

TECHNOLOGY AND THE RHYTHM OF ACCUMULATION

The technological determinist views of growth now in vogue are the product cycle for individual industries (Burns, 1934; Kuznets, 1930; Vernon, 1966; Hirsch, 1967) and the wave of innovations view for whole epochs (Mensch, 1979). The evidence does not support either. There is no universal S-curve of growth; sectoral output grows in a variety of patterns (Gold, 1964). Growth paths are characterized by revivals as much as declines, by short-run business cycles as much as long-run patterns. On an aggregate basis, long swings in economic growth bear no obvious relationship to "bunching" of innovations (Freeman et al., 1982).

From what has already been said, what might we expect of the strictly technological contribution to temporal growth patterns? Because technical change is levered, lumpy, and unpredictable, we would expect its effects to be jerky despite the incremental nature of innovative activity or broad structural patterns of development. Nonetheless, structural breakthroughs may open up substantial periods of growth. Such growth might well take a wavelike pattern of upswing and exhaustion of technical change within a distinct design structure in an industry. Because breakthroughs are possible, we would not expect an organic pattern of maturity and decline in most cases, but a process of periodic renewal appearing either as a series of cycles or relatively continuous long-run growth (see Gold, 1964). The chance element in creativity also may lead to clusters of innovations that give shape to a period of growth (Sahal, 1981: 57-60). Finally, technical linkages and common principles across a range of industry means that a major structural breakthrough and period of evolution in one field may trigger a broad front of growth, as is now happening with microelectronics (Freeman et al., 1982; Nelson and Winter, 1977; Rosenberg, 1976; de Bresson and Townsend, 1978). We should not be lulled, however, into forgetting the disjointedness of technical change, the lags and unevenness of application, the odd pathways down which it moves, the multiple waves of innovations, and even the reversals, all of which roil the surface waters and render underlying wave patterns of technical change consistent with a highly incongruous set of events in different industries.

The structural patterns of technology have force in the development paths of industry simply because production involves physical products, techniques of production, hardware, and a division of labor, and capital must take a "fixed" form as productive and commodity capital (Harvey, 1982). As Rosenberg (1976: 110) says, "the technological level has been more badly neglected than the economist generally recognizes."

Conversely, technical change depends on the other conditions of capitalist growth. From what we know of the process of technical change, we can see the multitude of openings for economic and social influence. The organization of production in profit-guided units linked together by markets obviously means that technical decisions are guided and mediated by market considerations. Moreover, its incremental, practical origins lay technology open to continuous input of cost and price information (David, 1975). Technology requires investment in fixed capital to be installed, so its rhythms bump against those of capital recovery over time. Markets rest on social conditions of consumption, distribution, and division of labor; market saturation, for instance, may be a spur to technical change. Technology is also a means of class struggle between capital and labor.

The rhythms of capital accumulation are themselves prime movers of technical change. Even if innovations are chance events, chances are increased by the degree of effort made, which depends in turn on the rate of investment—and not just R&D. Growth itself means accumulated learning, pressing problems to solve, and the will to tackle them (Sahal, 1981: 110, and references cited there). A notable case is the way postwar Japanese steel makers, pressed by booming growth, broke through supposed technical barriers of scale (Gold, 1979). Indeed, a mere increase in scale through growth demands change in technical structure (including division of labor) of an activity (Sahal, 1981: 65-69; cf. Gould, 1980). Schmookler's (1966) well-known data on innovation actually do not show "market pull" determining technical change, but innovation by learning and adoption by level of investment (Rosenberg, 1976: 260-279). In part, then, growth generates its own technical change; it is self-generative.[23]

In the end, the most fruitful way to look at the problem is in terms of the dialectic between the technical relations of production and value relations, as Harvey (1982: 135) suggests.[24] There is a whole constellation of things that must be in place for accumulation to proceed: labor-power, the money and credit system, market institutions, business organization, and so forth. Despite his great attention to technology, Marx treated it as only one limb of the beast to be studied (Mandel, 1975; Harvey, 1982). Even Schumpeter (1939), considered the father of the technical determinist theory of capitalist growth, actually had an extraordinarily rich conception of the conditions for accumulation, which has been lost in the work of most of his followers.[25] It has been widely noted that periods of growth seem to involve distinct "regimes of accumulation," or growth ensembles (Lipietz, 1977; Gordon, 1978b; Mandel, 1975; Walker, 1981b). To my mind, Schumpeter's (1939) fully articulated analysis amounts to the same thing. The technological system is a fundamental component of such regimes, even if it is not, by itself, the prime mover. It is clear enough how important the railroad and the automobile were to the constellation of conditions of capitalist growth in their respective centuries; or Taylorist and Fordist labor processes; or means of communication such as the telegraph and computerized digital flows. But none of these reduces strictly to a "technology," (i.e., it is institutionalized in other social practices) and none may be said to be *the* source of growth. In short, it is the pattern of accumulation that is the central thread in capitalist growth, not the technology, labor process, or any other single part of the system.[26]

One must also be careful about the image of a structure of accumulation, which implies a rigid functional system of well-fitting pieces, like a tinker-toy. Internal imbalance is a creative force that helps propel the system forward (Harvey, 1982). Thus, in the tension between technology and value lies the potential for both growth and crisis. A better image is one of a system moving along under the force of several driving gears that mesh but one tooth at a time, with much grinding, shaping, spinning, and halting of gears along the way. And, although it can get up speed, it may also grind to a halt as the gears fail to mesh harmoniously under the more and more demanding conditions of rapid growth.

Growth cycles do not turn down, therefore, merely as a result of the diminution of technical change, as epochal technology or big bang theories imply. It might just as well be due to the inability of the system to accommodate an increasing rate of technical change (Harvey, 1982). Downturns also come because of imbalances between sectors, between production and consumption, between labor and capital shares, between money and production. The interesting question is how parts of the system get on the wrong track, out of synch with the others, whether it is a pattern of oil consumption that creates the potential for OPEC's revolt or a pattern of labor bargaining that runs up against the need for automation and wage reductions to meet world competition.

Such contradictions principally develop through the process of overinvestment in the wrong avenues of development, whether in too much steel that is no longer needed or in too many nuclear power plants that don't work (Devine, 1980). The imbalances eventually show up in an overaccumulation of one or more forms of capital and lead, ultimately, to crisis if rapid corrections cannot be made (Harvey, 1982).

THE EFFECTS OF TECHNICAL CHANGE

Given the above perspective, we can quickly lay to rest any simple notion of the necessarily beneficial effects of technical change. First, not all technical change is beneficial to capital accumulation. Nuclear power is a prime example. Second, capital accumulation is the issue, not the growth of any other variable, whether employment, income, or personal self-realization, although such growth may accompany accumulation for any number of reasons. It is readily apparent that automation may eliminate jobs, shifts of the division of labor may mean the growth of low-paying jobs, a product innovation in one sector or one country may have its biggest impact elsewhere, cyclical unemployment can destroy people's lives, and so forth.[27] Therefore, the road from innovation to desired social result can be tortuous, if not altogether impassable.

TECHNOLOGY AND SPATIAL PATTERNS OF DEVELOPMENT

We can now add the spatial dimensions of industrial anatomy, technical change, and growth, using the preceding conclusions to guide us and adding new twists that a spatial treatment of accumulation demands. We will see that none of the prevailing views of the regional or locational impact of technical change holds without qualification.

THE SPECIFICITY OF INDUSTRIES AND THE SPATIAL DIVISION OF LABOR

Industries are different and technology plays a big part in those differences, as previously argued. Hence, they have divergent locational needs, whether for a particular material or a particular labor force. As Sayer (1984: 25) puts it, "industry is incredibly complex and differentiated and so too are its products and hence its cost structures, and hence in turn its locational patterns." This complexity is compounded by the divisions among work units within companies and within industries.[28] It makes all universal statements about location patterns immediately suspect, for the primary pattern to grasp is that of a fine mosaic of industrial places.

If industries start from different conditions and follow different development paths because of their technology (as well as their history of labor relations, marketing, etc.), why would we expect them not to start in different places, move differentially, and end up in widely diverse places? All that is required is that the spatial distribution of conditions of production be uneven. This is the valid starting point of Weberian location theory that was lost in the subsequent fixation on transportation and marketing, homogeneous plains, and homogeneous production functions (Losch, 1954; Isard, 1956). But one cannot end with Weberian theory, which takes linkages as given, sees technical change only in terms of factor substitution, treats labor as a one-dimension commodity, and has no theory of economic growth. My position on these topics has already been stated; it will be further amplified as we proceed to consider some theories that go beyond Weberianism in these areas, but still come up wanting.[29]

An issue I have not previously introduced, on which Weberian theory also fails, is the interaction between geography and industry. Weberian models allocate industries to places based on their factor endowments. But there are no such initial conditions once industry is in place.[30] Industry evolves along with places. First of all, industries have a tremendous influence over the spatial distribution of factors of production: they draw labor through migration, they create markets for other industries, they intervene in local politics, and so forth (Piore, 1979; Walker et al., 1981). In other words, industry *produces* industrial space to a considerable degree (Storper, this volume). Geographic unevenness of "factor endowments" is continually recreated by industry's use of space, which affects future location decisions (Massey, 1978, 1983).

Second, preexisting spatial configurations not only steer industry to a spot, they also alter the way industry develops. Geography adds another dimension to industrial evolution. Consider strategy: Companies may seek lower cost either through technical change or by relocating to cheaper labor. The outcomes of such moves become the preconditions of future decisions concerning technology, labor relations, and location. And because technology and labor relations evolve incrementally through experience, such steps are, to a large extent, irreversible; one cannot jump back onto the road not taken (Storper and Walker, 1983). In short, industry growth paths are altered by spatial practice. As a result, one will often find geographically distinct technologies and labor practices within a single industry—especially across national boundaries (Gertler, 1984; Storper and Walker, 1983; Brittain, 1974). At the same time, regional growth paths depend on the way industry develops in places.

Because the technical factor is essential to the character of industries and their locational needs, it should be possible to make some statements about the relation of types of technologies and industry location patterns. One such approach is to use production-based categories such as batch versus continuous flow processing (Storper, 1982; Storper and Walker, 1984). But one must not exceed the limits of what can be said about underlying technological patterns versus empirical geographical regularities. Some limitations are due to the disjunction between structure and outcomes, given intervening contingencies in each particular circumstance; these impede empirical generalization, but not statements about underlying patterns (Sayer, 1982b). Too many things intervene to break the tidy connection between technology and the shape of an industry and between industry structure and its spatial strategy (e.g., the talents of Henry Ford compared to failed car makers who located elsewhere than Detroit). But some of the disjunction involves structural transformation in technology and industry because of their geographic history. The substantial differences between the English and the American automobile industry can be put in no lesser terms.

A case of inappropriate generalization is the search for the golden fleece of the locational patterns of high tech industry. Why should we expect certain shared technological characteristics, such as rapid product development or high automation, to have uniform locational effects across otherwise different industries? Why would electronics in Japan conform to electronics in the United States, given their very different social bases? The search is rendered even more problematic by the uncertainty surrounding the category of high tech itself. Does it refer to product, process, or division of labor? To the rate of technical change? What sort of scale of high and low technology is used? What definition of industry? These may not be insuperable barriers to an analytic meaning for high tech, but the theoretical work is not there as yet.

Are there no broad patterns to the diversity of the spatial mosaic? It will not suffice to end with a plea for specificity alone. Among those who have broken with the neoclassical model of regional specialization of industry and equilization of income, models of spatial hierarchy are popular. Such hierarchies are commonly measured in terms of degree of urbanization, labor skill, sectoral levels (extractive/manufacturing/services), or place in the corporate organization chart (Massey, 1978; Lipietz, 1980; Stanback and Noyelle, 1982; Aydalot, 1981).[31] These models go beyond the Weberian theory of location and its conception of linkages, labor, growth, and technology. In particular, there are three main ways of getting from technology to geographic hierarchy: agglomeration economies, technological maturation, and innovation-diffusion.[32] I will examine each approach at length, and find all wanting, despite obvious areas of application.

AGGLOMERATION

Agglomeration theory is a powerful, if somewhat vague, notion. The idea is that spatial propinquity allows better access to the inputs and outputs necessary for production, thereby raising revenues, lowering costs, and increasing productivity (Hoover and Vernon, 1959; Pred, 1966; Gilmour, 1974). Two aspects of this will be dealt with here: commodity flows (linkages) and labor pooling.[33]

The traditional emphasis in commodity linkage analysis has been on transport costs. Given the friction of distance, proximity gives access to larger markets. This, in turn, allows certain economies of scale in production. While this may have had a certain bearing in the past (Moses and Williamson, 1967), it carries less force today when transport and national markets are so well developed (Storper and Walker, 1984). Yet agglomerations persist. Attention has, therefore, turned to the character of the linkages as well as their mere mass: specialized markets for customized goods, where personal contact and a rapid flow of information are essential (Hoover and Vernon, 1959; Vernon, 1960; Scott, 1982a, 1982b) and technically linked industrial complexes (Castells and Godard, 1974; Norton and Rees, 1979).

Because custom markets and strong technical linkages do not exist for all products, agglomeration cannot be held a universal tendency of industries. Scott (1982a, 1982b) distinguishes two groups of industry: large-scale materials-intensive and small-scale labor-intensive. The former do not depend on agglomeration because they process large volumes of inputs for mass markets, so their linkages are regularized and they get volume discounts on transport. The latter are characterized by a high division of labor, many small exchanges, and customized work. Scott's contribution is to make exchange linkages depend on the character of production, rather than vice versa. It puts technology at the center of agglomeration theory.[34]

But this model will not suffice. For example, sometimes mass production leads to agglomeration, as where there are direct technical linkages (e.g., petrochemical complexes). But the physical ties of chemical pipelines are not the rule. Should we assume that the Detroit auto complex is based on mere physical connections between assemblers and parts suppliers in a linked production system? A territorial complex based on skilled machining is probably a better explanation (Norton and Rees, 1979). On the other hand, mass production (with flexible automation systems) may be consistent with a dispersed production system, as is happening in the Italian auto industry (Murray, 1983). Despite Scott's good efforts, the determining forces of spatial integration-disintegration of the division of labor remain in need of a great deal more theoretical work, after years of neglect.

The geographic scale of agglomeration also has not been carefully addressed. What is the effective range of proximity? If it is "the manufacturing belt" (Norton and Rees, 1979), it borders on solipsism; all distinctions between big cities, systems of big cities, and regional complexes of small towns is lost (see Vance, 1977: 330-35; Pred, 1980; Muller, 1977; Pudup, 1983). Is Silicon Valley a periphery of San Francisco or a core in its own right—or both, depending on what connections we are examining?

Commodity linkages are not enough, of course. Scott tries to tie them in a determinate way to labor demand, arguing that large-scale, materials-intensive industry requires less skilled labor, while small-scale, labor-intensive industry requires more skill. This is the basic formulation of agglomeration economies as regards labor: It takes density to produce an adequate pool of skilled labor, which is in high demand and short supply. Such pools of labor both restrain wage increases and assure supply, and they work to the advantage of workers looking for jobs as well as firms looking for workers. If we take a sufficiently broad view of labor, this pooling of skill among managers, engineers, financiers, and traditional blue-collar skilled workers is a major reason for the agglomerations in Silicon Valley or around Wall Street. But there are cautions here as well.

The treatment of labor demand in agglomeration theory as either skilled or unskilled is reductionist, involving a kind of technical determinism. As previously discussed, labor requires a richer conception of performance, control, and reward (Storper and Walker, 1983). Problems of labor control and cost, especially under a regime of collective bargaining, may make wage demands higher in urban areas because of militancy and "pattern bargaining," leading some industries to seek out dispersed locations. Storper (1984) suggests that the state of labor relations in Brazil generates a more concentrated pattern than in the United States. On the other hand, labor control may be best secured in dense settlements, such as immigrant ghettoes. The definition of skill is also more problematic than it first appears. The so-called unskilled at the periphery may not be a usable workforce if they haven't sufficient industrial discipline.

Nor can labor and linkages easily be joined in a technically determinate way. Part of the reason for the agglomeration of electronics firms in Silicon Valley is the vigorous web of linkages among component suppliers and product assemblers; this seems to depend strongly on the type of final products, such as computers. In cases in which there are few linkages, such as the space communication systems of being built in Melbourne, Florida, there is little agglomeration, despite the presence of a huge pool of technical labor (Glasmeier, this volume).

Agglomeration theory has the virtue of simultaneity; that is, it goes beyond the partial equilibrium of Weberian theory.[35] Agglomeration theory touches on the active creation of spatial organization by industry. But it does so in a very limited way, through contiguity, not strategy. It misses the possibility of action at a distance and of the active intervention of business in labor markets, local politics, and the like. Industry does not depend only on the passive action of the market, distance, and the cumulative weight of many industries to make places suitable for its purposes.

At the same time, agglomeration theory has a limited conception of feedback from spatial organization to industry. It usually includes some notion of diseconomies of agglomeration, which is a catch-all for such things as rising labor costs, militancy, and traffic congestion. Although there is no question that such things happen, and may lead to industrial decentralization (Saxenian, 1983), this weak formulation gives little indication why and when such effects take hold. Moreover, both agglomeration and disagglomeration are normally seen as simply shifting conditions of factor supply, rather than as altering the shape of technical change and industrial development itself.

TECHNOLOGICAL MATURATION AND RELOCATION

It is frequently argued that technical change results in the dispersal of workplaces from core industrial areas.[36] I will consider two reasons for such decentralization.[37] The first theory of decentralization is that the maturation of production processes—greater standardization and mechanization—breaks the bond of dependence on skilled labor and allows industry to seek out cheaper, unskilled labor supplies in peripheral regions (Hoover, 1948; NRPB, 1943; Vernon, 1960, 1966; Hirsch, 1967; Norton and Rees, 1979). While many times this does happen, there are so many exceptions that it does not serve as a valid generalization. Both the major process and the intervening causes need to be formulated more carefully.

First, the idea rests on an organic notion of growth and maturation of technology that needs to be sharply circumscribed. Technical change does not unfold in such a simple, universal, and unproblematic way, for all the reasons previously discussed. Some industries never move beyond the craft or small batch stage and remain tied to skilled labor, for example, medical instruments (Hekman, 1980b). Some go looking for cheap labor precisely because they must achieve mass production without mechanization, for example, U.S. semiconductor assembly in the Far East. At the same time, the Japanese took the route of mechanization for better quality control and did not disperse production. Sometimes industries revert to more customized production because of product innovations, for example, the recent bloom of custom microprocessor producers in Silicon Valley.

Second, labor demand does not follow so easily from technique. Increased automation may lead to a type of reskilling and recentralization, as is likely for U.S. semiconductor assembly. Specialized skills developed by a long-standing industry-labor relation, rather than skill in general, may be the issue (Sahal, 1981: 59). Why else do certain industries, such as jet engines, cling to particular centers despite considerable production change over time (Storper, 1982)? Moreover, the demand for labor does not reduce to skill. Relocation may occur for reasons of labor control without technical change, although ordinarily both control and technical change are involved in decentralization (NRPB, 1943; Massey and Meegan, 1982). Conversely, successful labor control can mean the avoidance of technical change and/or relocation.

Third, the supply of labor is not given in the fashion assumed by the product cycle model. The distribution of skills is not a simple gradient from a skilled center to an unskilled periphery. In the past, the northeast and midwest United States were dotted with industrial towns making everything from shoes to farm implements and benefitting from the influx of skilled European immigrants (Lindstrom, 1978; Pudup, 1983). On the other hand, some of the cheapest labor has always been found in the central cities. Then, of course, labor can migrate to or with production. Skilled labor often is relocated along with new plants (Pratt, 1911). Differential mobility of labor segments makes the decision more complex: Medium-range skilled technicians are often the least mobile and most sought after labor force (Oakey, 1979).

Finally, both the active recruitment policies (Piore, 1979) and the ongoing employment practices of industry (Storper and Walker, 1983) shape the local labor force. Conversely, the experience industry has with labor and other local conditions shapes its development path; production does not dictate location in a strictly linear way.

Textiles are the classic case of relocation to cheap unskilled labor in the South. Hekman (1980a) makes a good case for a product cycle interpretation of this shift. Nonetheless, there are difficulties. Mechanization advanced for 50 to 100 years before it resulted in the kind of deskilling the model anticipates. Even then, some skilled workers were exported to the South along with the new plants: Why could this not have been done earlier? And Hekman treats the designation unskilled as completely unproblematic, as if there were nothing to making agrarian folk into industrial workers (Thompson, 1967). Carlson (1981) opposes this view, arguing that Southern textile makers tended to cluster in areas where industrial experience was greatest. In fact, the industry had built a base in the South going back to the 1840s and grew rapidly by 1860—long before the technical maturation Hekman argues for. Did slavery have any affect on labor force and industrial development in the South before 1865 (Genovese, 1967)? Why did many skilled workers who set up operations in the South fail before 1880? Nor is labor control in the North, rather than simply skill, given more than passing consideration (Hekman, 1980a: 711). Why were a series of labor forces, from mill girls to Greeks, brought in over the years if labor cost and control were not already an issue in New England? Finally, it will not do to treat technical change as essentially complete by 1910, as Hekman does. Why hasn't the synthetic/knit revolution resulted in a locational shift as profound as the one circa 1900? It appears that one must take a closer look at why capitalists gave up on the workers of New England after a century and found a suitable replacement in the South at the time they did. They may have even pushed technical change to accommodate this strategy. In any event, technical change may have made the shift possible, but it cannot bear the full weight of explanation.

The second explanation of decentralization is the lessening pull of interindustry linkages on large, standarized operations. The parallel between delinking and deskilling is commonly observed (NRPB, 1943; Hoover, 1948; Vernon, 1966; Hirsch, 1967; Hekman, 1980a). Scott (1982a, 1982b) again tries to tie the two together in terms of production changes. Mass production means greater integration of formerly scattered units and greater throughput of materials; hence, larger, more regularized markets and bulk discounts. Industries thus move from small-scale, labor-intensive to large-scale, materials-intensive.

But, for all the reasons previously cited, we must be cautious about imputing such a pattern to all industries. Products, especially capital goods, do not all mature to mass consumption items. Process does not evolve single-mindedly to mass production. So all industries cannot be expected to go through delinkage—even if they begin in an agglomerated state. More troublesome to the delinking hypothesis is the occasional evidence of *increased* agglomeration accompanying greater integration and scale of production, as in the case of automobiles in Detroit in the 1920s (NRPB, 1943: 101) and textiles near Boston in the 1810s through 1840s (Vance, 1977: 333). Is it a result of the elimination of more widely dispersed smaller competitors (the opposite of Scott's scenario of large plants driving out more agglomerated small firms)? Or is it that large plants in some industries have powerful agglomerative effects, drawing around themselves small suppliers and such (Oakey, 1983; Glasmeier, this volume)? That depends on the linkage characteristics of the particular industry, which varies by technology and social practice in production, product, and division of labor. One cannot simply read linkages off from production technique. Note, for example, the reconcentration of some American industries (e.g., Caterpillar tractor), production methods unchanged, in order to imitate the Japanese practice of Kanban, or rapid delivery of parts without holding large inventories.[38]

Hekman (1980a) adds that the crucial link in New England textiles was to the producers of textile machinery, who needed to be in close contact with customers and who relied on skilled labor more than textile makers themselves. Only as machine making became standardized and mechanized was it possible to break this link and move textiles south (often keeping machine making in the North). In light of the evidence about machine makers and technical change, this is a powerful argument (and used to good effect against the water power site theory of textile location). Nonetheless, one wonders why the changes in machine making, which were widespread, did not lead to similar moves south among a wider spectrum of industries. Again, it must be said that we have little theoretical guidance as to how to grasp these variations in the development of markets, linkages, and agglomeration/disagglomeration.

INNOVATION AND GROWTH

A major school of thought sees growth as the simple product of technical innovations, which spring from urban-industrial agglomerations and diffuse from there (for reviews, see Pred, 1973; Malecki, 1983). This raises four issues: the site of innovation, where innovations are taken up, the effects of innovation, and the role of innovation in growth as a whole.

Innovation springs chiefly from industrial practice, not spatial proximity in general. While industrial concentrations may generate a great deal of innovation, rapid technical change also occurs in industries with a more dispersed location, such as farm implements (Pudup, 1983). The rate and character of innovation depends heavily on the industrial base, and there is no necessary relation between innovative capacity and agglomerative location pattern. The link is usually made on the basis of concentrations of skilled labor or information, but the practical limits of products and production have more impact on innovation than skill or knowledge in general. As Chinitz (1961) observes, Pittsburgh's heavy industry complex colors, and limits, the possibilities of innovation. Similarly, the Midwest, as a center of metal working, is most likely to generate innovations of this type, rather than be a center of innovation in general, as Norton and Rees (1979) imply. Tests of the "incubator" hypothesis indicate that innovation (new firms, new growth) takes place in central cities chiefly when that is already the preferred locus of the industry (Struyk and James, 1975; Leone and Struyk, 1976; Cameron, 1980; Nicholson et al., 1981).

To the extent that innovations flow from organized R&D work—which is uncertain—they will appear in the preferred locations for such work. While R&D is highly centralized, it also has specialized labor demands by industry and linkages depending on whether it is market, process, or basic science oriented (Malecki, 1981: 315, 317; Gold, 1979).

Clearly, however, innovation does not just reinforce existing practice and is not necessarily used in the same place it originates. There is a chance element in the spatial as well as the temporal incidence of innovation and its spread. But systematic influences also operate. The markets and linkages of an industry have a great effect on the paths down which change travels. They particularly affect the potential for spinoff products and firms; the multiple component and market niche character of computers makes them a prime spinoff generator (Glasmeier, this volume).

More generally, the industrial environment of an established center, in terms of the domination of labor, capital, and linkages by one industry, may stifle the development of new activities in any number of ways, as Chinitz says of Pittsburgh.[39] The search for an environment of its own, a clean slate—especially as regards labor—is probably a basic reason behind the tendency of so many new industries, from automobiles in Detroit to semiconductors in Santa Clara County, to seek out new pastures for development. Once there, they reproduce the conditions of their own growth for a time (Storper and Walker, 1983; Saxenian, 1983; Christopherson, 1982; Scott, 1984). This is a much more far-reaching reason for industrial dispersal than is technical maturation. Its result is a temporal sequence of places developed in concert with particular industries or industrial complexes (Watkins, 1977; Gordon, 1978a; Walker, 1981). The mosaic of unevenness thus rests in time as well as space.

Of course, the identification of technical change with local growth is too easy. As the literature on branch plants has amply documented, the beneficial effects of growth may be felt far away (e.g., Pred, 1977; Erickson and Leinbach, 1979). This is not because branch plants are lacking in technical change (e.g., semiconductor plants in Phoenix) (Sayer, 1984), but because the effects of technical change depend on the labor force, type of process, linkage patterns, and so on. For example, process change may reduce employment at a site, or it may spur relocation; product innovation may prompt investment in a wholly new line, produced at a different plant.

Finally, a shifting division of labor within industries may be the most important technical change as far as spatial patterns of growth are concerned. Not many places can link their star to the microelectronics industry, with its rich harvest of spinoffs; indeed, net new firm formation is a tiny percentage of overall growth (Malecki, 1981). For most places, the prospect is of capturing a limb or two of the industrial system. In the complex mosaic of industrial location, almost every facility is a branch plant. That applies even to R&D labs, which are normally not the places where the growth spurred by their innovations occurs. Yet, regardless of what R&D labs actually produce, they are good things for local growth because industry is investing a lot in them and hiring high-paid labor to work there. In other words, it is probably more important to attract investment in expanding segments of industry than to spawn new industries. The benefits of capitalist growth depend on where surplus value ends up, not where technical change begins.

At a larger scale, where regions develop on the basis of a diverse industrial system, growth has broader and deeper roots than technical innovation, contrary to the view of Norton and Rees (1979). Self-generative regional development involves the generation, retention, and investment of surplus value, the development of a capable, diverse workforce, the interaction of a range of industrial activities, the creation of a suitable social and physical infrastructure, an energetic and growth-oriented state apparatus, and the like. That is, it requires a workable growth ensemble. A few places achieve something like this ideal—although no region is completely self-contained and not every place that is broadly suitable will, in fact, sustain growth. All of the famous examples of rapid regional growth in the United States—early nineteenth century New England, the late nineteenth century Midwest, twentieth century California, late twentieth century Houston—had long years of prior development, including agriculture, mercantile trade, and accumulation, a home market, government promotion, and various humble industries such as food processing (see, for example, Pred, 1966; Pudup, 1983; Platt, 1983). Although they benefitted in many ways from the antecedent growth of more advanced regions, they did not depend primarily on branch plants or technological spinoffs for their growth. Capitalism is not monolithic and it has shown its capacity to generate growth, including technical innovation, on fresh soil on numerous occasions.

CONCLUSION

In sum, technology has a significant effect on industrial location and the course of regional development, particularly in the way it shapes the distinctive character and growth path of industries. Nonetheless, we must eschew technical determinism as a mode of analysis. Neither logic nor evidence sustain most prevailing theories of broad spatial patterning based on technological forces. Too many other variables intervene in the open system of the space-economy for sweeping generalizations about the effects of technical patterns to be borne out. We need a more supple approach to technology and its geographic effects. Geographers must, therefore, employ a structural-realist mode of analysis that takes cognizance of technology as one of the basic structuring forces of the industrial system, but puts it in proper relation to other elemental structures of capitalism (such as class and competition), allows for human agency and the many contingencies of history, and inserts space into the process of industrial development (see Sayer, 1983). In short, geography cannot be read off from technology.

NOTES

1. I do not take up the important questions of market and business organization or of the circulation of money and capital, except peripherally.

2. Ordinary neoclassical economics has no technological determinism because technology is not regarded as an interesting problem. Choice of techniques is a static process of weighing relative prices of labor and capital. This Hicksian view of price—induced factor substitution, in which technique (and capital equipment) is treated as perfectly malleable, has been exposed to withering criticism (Kennedy and Thirlwall, 1972). From one side, it has been argued that capitalists do not cost minimize by choosing one factor over another (Salter, 1966); besides, technical change is lumpy and balancing factor prices is a pipedream (Rosenberg, 1976: 61-84). From another side, it has been argued that the price of capital is a fiction, which cannot be known without prior knowledge of technical coefficients and the distribution ratio between capital and labor (Hunt and Schwartz, 1972; Harcourt, 1972). For my part, I have always wondered why, in a neoclassical world with perfect substitution, homogeneous production functions, and perfect markets, all industries do not converge on an identical technique. And, indeed, in his attempt to defend neoclassical capital theory, Samuelson ended up having to assume a world in which all industries have the same labor-capital ratio (Harcourt, 1972).

3. Technology typically refers only to products and processes of production. This begs the question of organization of production and circulation, except where it sneaks in the back door by reference to the "technical division of labor" or "market"—as if either were not the problematic result of human institution and choice. In this chapter I continue an extended argument for the importance of the division of labor as a structural category of economic analysis that cannot be reduced either to process/product, class, market, or corporations (Walker, 1985a, 1985b). The division of labor must be included, along with both market and corporate forms of organization, among the whole range of the forces of production. The organization of production and circulation is very much structured by technical problems of transforming nature and rendering it useful (and accessible) to people, independent of the structuring influence of class and power (the social relations of production). I will often use the word "technology" to encompass the division of labor and organization of production as a matter of convenience, given the clumsiness of the phrase "forces of production."

4. The distinction between use and use-value parallels that between exchange-value (price) and value (see Harvey, 1982).

5. A slightly different case is the resource-based industries, which have certain problems of extracting resources from the earth in common and, therefore, share some developmental characteristics (Markusen, 1983; Perloff, et al., 1960).

6. It should be clear that what has been said in the previous section about technical linkages, imbalances, and innovation applies both within and between industries.

7. Von Tunzelman's (1978) study of steam power in the industrial revolution vindicates Marx's analysis.

8. Although the notion of deskilling has had, since Adam Smith, a certain purchase among mainstream economists (see NRPB, 1943).

9. Marx also touches on two dimensions of the labor process that need greater development: the transfer of materials from one step of processing to another (Storper, 1982) and the monitoring of process, movement, and product quality (Bright, 1958). These

become increasingly important with continuous flow, integrated machine systems, and assembly-line processes and with electrical/electronic control systems, or what commonly comes under the heading of "automation." In general, we need a better grasp of chemical and electronic process improvement, comparable to the treatment of mechanical systems.

10. Of course, there are also generalizable principles involved in the physical processes of production—which is why one can speak of "technological systems" based on epochal technologies and families of machines. But these are not as widespread as the principles of division of labor or mechanization.

11. It is by no means obvious at any time which of several available techniques is best; indeed, even the physical efficiency of any process is hard to grasp in a single, comparable measure (Gold, 1979).

12. There is also a good deal of unevenness in the mechanization and automation of various steps in production (Bright, 1958; Kinnucan, 1983).

13. The labor-saving bias is augmented by considerations other than cost, of course, especially the preference of capitalists for docile machinery over refactory people.

14. Piore (1968) found a consistent class bias of engineers against labor-intensive methods. But he also emphasizes the priority of technological imperatives over careful weighing of labor considerations in the development of production.

15. The following rests heavily on my reading of Rosenberg (1976: especially 189-212, 108-125; 1982: 55-80), David (1975), Nelson and Winter (1977), Sahal (1981), Gold (1976, 1979), and Piore (1968).

16. I use the term "science" here in the way it is commonly understood in the literature, as theoretical laboratory research. If the term is broadened to mean the systematic use of mechanical, chemical, or electronic principles, rather than relying on the traditional knowledge of the worker about a craft, then, of course, science is applied constantly in modern industry (Marx, 1967; Rosenberg, 1976: 126-138; 1982: 141-163).

17. Indeed, excessive social stratification and lack of communication between high-level engineers and lower-level people often blocks technical change.

18. There are, however, considerable problems in dating innovations (Rosenberg, 1976: 72; Freeman et al., 1982: 45-51; Gold, 1979).

19. There is a common misconception that processes are mechanized of a piece, when they are, in fact, unevenly developed; highly sophisticated technology may rub elbows with wholly manual operations (Bright, 1958; Kinnucan, 1983; Piore, 1968).

20. Such effects are felt in the price sphere as well, even where there are no direct technical complementarities at work.

21. Within a basic structure of product and production there is likely to be an evolution of the labor process toward greater mechanization if markets are expanding (Abernathy and Utterback, 1978).

22. And they are often overlapping because old products in the same industry do not necessarily die out as the new come in (e.g., blenders versus cuisinarts).

23. However, full capacity utilization does not always appear to be conducive to experimentation, so innovations may come earlier and later in the business cycle (Mansfield, cited in Sahal, 1964: 118).

24. Only the net can be cast more widely to include use-value relations of commodity consumption and work, in so far as these cannot be strictly reduced to either technology or value.

25. Mandel has also sometimes been interpreted as a technological determinist, wrongly I think.

26. Although we should be able to rank the overall importance of different parts.

27. On the other hand, one should not leap to hasty conclusions about cause and effect, given the many technical and nontechnical sources of interaction in the system; automation of manufacturing, for example, need not lead to permanent unemployment if it stimulates additional product demand through falling cost, generates linked demands for materials and equipment, and is accompanied by investment of surplus profits in other sectors.

28. Having already made the point about the difficulty of defining industries, I need only say here that the word "industry" is used in full cognizance of the problems.

29. My target here is not directly Weberian theory, but most of what follows applies to it as well. For more on Weberian/neoclassical themes, see Walker (1981), Walker and Storper (1981), and Storper and Walker (1983).

30. Nor before, given the social workings of preindustrial capitalism or other modes of production.

31. There are serious problems of specification in most such models that I cannot pursue here. The measures are often poorly theorized (e.g., "services"—see Walker, 1985b) and the frequently assumed correspondence among different measures by no means always obtains (e.g., between urban and corporate hierarchy—see Pred, 1977).

32. In my view, product cycle theory is a way of tying the three together, not a separate theory. I am currently working on a full critique of the product cycle.

33. Innovation, which is included in some models of agglomeration (e.g., Pred, 1966, 1973), is considered separately below. Other agglomerative forces, such as finance and information, are beyond the scope of this chapter.

34. A similar connection is implied, if not explicit, in the work of Hoover (NRPB, 1943; Hoover and Vernon, 1959), who is also very sensitive to the importance of changing marketing arrangements (e.g., via merchant houses) as well as volumes. However, some would argue that the organization of commerce is more important to agglomerations than product characteristics or technical linkages.

35. It thus avoids such foolishness as attributing all location to market pull, when industry is its own biggest market. It also speaks to a world in which raw materials are a small portion of inputs and of diminishing influence on location (Perloff et al., 1960).

36. It is usually assumed that such relocation starts from an initial agglomeration, although that is by no means always true.

37. Other factors, such as availability of space in cities, cannot be dealt with here (see Walker, 1981). I agree with Scott (1982a, 1982b) that they are secondary to the matters discussed here.

The main neoclassical theory of decentralization is that transportation costs have fallen and flexibility has increased via the truck. Although improved means of circulation have undoubtedly made greater dispersal possible, they have not determined it (Walker et al., 1981; Storper and Walker, 1983; Scott, 1982a, 1982b). It all depends on what kinds of transport needs industry has. The demand for transportation has an effect in the timing, if not the shape, of the technology of transport (Walker, 1978). Even Chinitz, who gave the truck theory of dispersal its major statement, soon cast doubt on it (see Chinitz, 1960, 1961).

38. My thanks to Phil Shapira for pointing this out.

39. Not only do changing industrial conditions demand changing regional circumstances, but the costs of past growth start to catch up with capital: labor militance, governmental regulations, deteriorating infrastructure, rising housing costs, and so on (Saxenian, 1983; Walker, 1981a).

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12

Technology and Spatial Production Relations: Disequilibrium, Interindustry Relationships, and Industrial Development

MICHAEL STORPER

☐ WHY DO MAJOR UPHEAVALS in industrial technologies and the location patterns and regional development paths that accompany them seem to take geographers, planners, and economists by surprise? Whether it be the decline of industrialized, high-income regions in advanced capitalist nations, the rise of new capitalist challengers such as Japan, the "miracles" in Korea and Brazil, the subsequent setbacks in Brazil, or the rise of new industries in altogether new types of spatial milieux, technological and spatial change is much less regular and often more dramatic than most of our theories would predict.

This chapter proposes a heuristic for analyzing the historical evolution of spatial production relations of industries. The purpose of this exercise is to establish the theoretical grounds on which we might begin to account for dramatic increases in the spatial capabilities of industries, based on the notion that we also must account for dramatic changes in technologies themselves. To do this, we must engage debates in both economics (technology) and location theory (spatial consequences of innovations); this chapter is a modest attempt to use some of the conceptual tools that have been developed in these fields to consider dramatic and long-run historical changes in technologies and location.

To get at this interaction between the process of locational change in particular industries, via particular innovations and strategies, and