Chapter 2
Technological Change: Dominant Design Approach

Abstract The cyclical model of technological change or dominant design model is based on the earlier dynamic models of technological change. These models such as product and process innovations, the transilience map, technological guideposts and creative symbiosis, technology s-curves plus evolutionary models are discussed first. Then the dominant design model and its elements, era of incremental change, era of ferment, technological change and dominant design are illustrated.

Keywords Dominant design model · Era of ferment · Technological change

This chapter which treats the theoretical background of the present study concerns the concept of the cyclical model of technological change proposed by Anderson (1988). This chapter also introduces dynamic models of technological change pertinent for Anderson's study. Moreover this literature review is essential in the re-examinations and re-testing of the cyclical model of technological change carried out in Chap. 5.

2.1 Anderson's Cyclical Model of Technological Change

This section discusses the cyclical model of technological change proposed by Anderson (1988). First, a concise review is devoted to the dynamic models of technological change on which Anderson (1988) based his model. Second, Anderson's model is discussed in detail. This sub-section also includes the definition of the concepts essential to the present study. The definitions for technology, innovation etc. are the same as those of Tushman and Anderson (1986), Anderson (1988) and Anderson and Tushman (1990, 1991).

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2.1.1 Dynamic Models of Technological Cycles

In the development of his dynamic model of technological cycles, dominant design, Anderson (1988) reviewed four dynamic models of technological evolution. Since Anderson had adopted certain features in his own model of each, all the models are briefly described. The first model, Abernathy and Utterback, is mainly based on three articles: Utterback and Abernathy (1975), Abernathy and Utterback (1978), Abernathy (1978) and Abernathy and Clark (1985). Three other models are those of Sahal (1981), Foster (1986) and Nelson and Winter (1982). Below is a brief review of these models plus Dosi's (1982) typology. Neither the above mentioned models nor Anderson's choices (i.e. the ideas from the above models included or excluded in/from his own model) are commented on or evaluated in the present study.

The models above are included in the present study because Anderson (1988) obtained several fundamental ideas from them. First, technology progresses in an irregular pattern, characterized sometimes by incremental and sometimes by major breakthroughs, which advance a technology past its previous limits. Second, these epochal innovations are followed by a period of de-maturity, experimentation and flexibility in R&D. Third, a dominant design or technological paradigm, or technical guidepost emerges, thus establishing the direction of future change along few natural trajectories, until some event triggers another change (Anderson, 1988:40). Anderson created his model of dominant design from the following reasons: "It (the model) allows us to understand different types of innovation in different industries during different periods using a common framework that lets us compare one to another" (Anderson, 1988:42).

2.1.1.1 Abernathy and Utterback

The Utterback and Abernathy (1975)/Abernathy and Utterbak (1978) model presumes that a major product innovation inaugurates the cycle. The output rate stimulated by minor innovations appears before the technology stimulated by major process innovation emerges. Abernathy and Utterback (1978) divided the Stage of Development into three patterns and named them the fluid, transitional and specific patterns. In the infancy of an industry (i.e. in the fluid pattern) firms are small, informal, flexible and entrepreneurial. The product line diversity arises from fundamental differences in technology. The competitive advantage is obtained by a technical superiority which allows a higher margin for their products.

According to Abernathy and Utterback, although many observers emphasize radical product innovations, process and incremental innovation may have equal and even greater commercial importance. The design usually creates a number of proven concepts and is seldom an advance in the state-of-the-art. The emergency of dominant design alters the pattern of technological change. The key technological development after a dominant design is cost reduction due to learning.

In 1985 Abernathy and Clark (1985) presented a new framework for analyzing the competitive implications of innovation. The framework is based on the concept of transilience, which means the capacity of an innovation to influence the established systems of production and marketing (Abernathy and Clark 1985:3). In the transilience map two diagonals—the extent to which an innovation disrupts existing production and operation competencies and the extent to which it disrupts existing marketing linkages—divide innovation into four categories: Architectural, Niche Creation, Regular and Revolutionary (ibid., p. 7).

Abernathy and Clark (1985) use the term epochal innovation in order to distinguish a radical innovation from an incremental innovation, which reinforces the existing tendencies in process development. An epochal innovation occurs with the introduction of an approach that cannot be produced effectively with the existing production processes. Clark (1985:112) says: "The essential issue in defining 'epochalness' is how a given innovation affects existing capital equipment, labor skills, materials and components, management expertise, and organizational capabilities." Niche creation and regular innovations are incremental and architectural and revolutionary ones are epochal.

Technological evolution in this transilience map-model goes counterclockwise from the northeast quadrant to the southeast quadrant (i.e. architectural, niche creation, regular and revolutionary). An architectural innovation opens market for new product classes. With the emergence of a dominant design the industry moves via the niche creation phase to the regular innovation phase. Abernathy and Clark (1985) cites Kuhn (1972), who suggests that the advancement of science is characterized by long periods of regular development, punctuated by periods of revolution. Historical evidence suggests that a similar pattern characterizes the development of technology, i.e. an epochal innovation can start the second round (referred to as industry de-maturity, Clark 1985:112–115) in the transilience map (Abernathy and Clark 1985:14).

Anderson does not use the three ideas included in these Utterback and Abernathy (1975), Abernathy and Utterback (1978) and Abernathy and Clark (1985) frameworks:

1. Anderson does not presume that product innovations typically inaugurate or dominate each cycle.
2. He abandons the notion that epochal innovations need not improve key performance parameters.
3. Anderson also abandons the presumed evolutionary path of technologies in counter clock wise from architectural innovation via niche creation and regular innovations to revolutionary one.

2.1.1.2 Sahal (1981)

Anderson mentioned that Sahal's model extends to concerns that are outside the scope of his work, for instance how breakthrough innovations arise, how long-wave economic cycles are linked to secular trends in national technological development, and how technologies diffuse in space and time. Anderson focuses on two key ideas: technological guideposts and creative symbiosis. The notion of technological guideposts can often be seen in one or two early models of technology which stand out above all others in the history of an industry. Their design becomes the basis for many innovations via a process of gradual evolution. The designs left imprints on a whole series of observed progresses in technology. Sahal uses Farmall and Fordson tractors and DC-3 aircraft as examples.

According to Anderson (1988), the concept of technological guidepost remains that of dominant design, but the emphasis is on how a standard imprints subsequent designs, not on the role of the standard in shifting an industry toward volume production (Anderson 1988:30). Anderson continues (ibid., p. 31), "a dominant design is a standard configuration that influences and constrains subsequent generations of a technology; it is not assumed here (in Sahal's work) that its dominance is based on its production in volume." Creative symbiosis is a situation where two individual core technologies have approached their limits and are then integrated to simplify the overall structure, thereby circumventing the limits to its evolution. In Sahal's work the empirical evidence comes from the farm tractor.

2.1.1.3 Foster's S-curves

According to Foster (1986), most of the managers of companies that enjoy transitory success assume that tomorrow will be more or less like today. Significant changes are unlikely, unpredictable, and they in any case come slowly. Foster's S-curve is a graph of the relationship between the effort put into improving a product or a process and the results one gets back from that particular investment. At the beginning, as money is put into a new product or a new process development, progress is very slow. Then something happens as more learning and the key knowledge necessary to make advances is put in place. Finally, as more money is put into development of the product or the process, it becomes more and more difficult and expensive to make technical progress. The S-curve sets the limit to a particular technology.

The quotation from Foster (1986:34) explains the importance of an S-curve. "If you are at the limit, no matter how hard you try you cannot make progress. As you approach limits, the costs of making progress accelerates dramatically. Therefore, knowing the limit is crucial for a company if it is to anticipate change or at least stop pouring money into something that can't be improved. The problem for most companies is that they never know their limits. They do not systematically seek the one beacon in the night storm that will tell them just how far they can improve their products and processes." According to Foster, S-curves almost always come in pairs. The gap (or the movement) between the pair of S-curves represents a technological discontinuity—a point when one technology replaces another. Rarely does a single technology meet all the customers' requirements and the many technologies compete with each other.

2.1.1.4 Nelson and Winter (1982) Model

Nelson and Winter (1982) do not take technology as given, which is opposite to the position of microeconomic theory. Traditional economics has also utilized maximizing assumptions which lead to equilibria. In traditional economics the equilibria are the pillars and the explanation of economic change usually involves a move from one equilibrium to another in response to an exogenous driving force. On the contrary, the firms in the Nelson and Winter evolutionary theory are treated as though they were motivated by profit and engaged in a search for ways to improve profits, although their actions are not assumed to be profit maximizing over well defined and exogenously given choice sets. This evolutionary theory emphasizes the fact that the most profitable firms drive the less profitable ones out of the industry; however, Nelson and Winter do not focus in their analysis on the hypothetical states of industry equilibrium in which all poorly performing companies no longer operate and the well performing ones are at their desired size. Nelson and Winter (1982:4).

Nelson and Winter (1982) stress the constant action of the natural selection mechanism over time, which winnows out less profitable organizations. Firms are not subject to a maximizing calculus in this model; instead, they have certain capabilities and rules which are modified over time, and which confer selection advantages or disadvantages. A key source of variation, which provides the material for selection to operate, is technological change. They say: "The core concern of evolutionary theory is with the dynamic process by which firm behavior patterns and market outcomes are jointly determined over time. Through the joint action of search and selection, the firms evolve over time, with the condition of the industry in each period bearing the seeds of its condition in the following period. It is precisely in the characterization of the transition from one period to the next that the main theoretical commitments of evolutionary theory have direct application." (ibid., 1982:18).

The influence of the work of Schumpeter in the Nelson and Winter evolutionary theory has been pervasive (ibid., 1982:39). Schumpeter was the first to develop a theory of economic progress that assigned a key role to technological change (Schumpeter 1934; Schumpeter 1942). The crucial matter in Schumpeter's analysis is the 'process of creative destruction.' If creative destruction is the driving force behind economic progress, then a theory of evolutionary economic change must take into account how technologies change over time and how industries adjust to technical advances. Nelson and Winter model this phenomenon.

According to Nelson and Winter, a technology has both economic parameters (which will affect its cost and/or the demand) and technological parameters (such as size, chemical composition) (1982:248). The R&D decision maker does not in general know the economic attributes (for instance how much the new technology will reduce prices or create demand). He knows at least some of the technical attributes. To find out more about the technical and economic parameters, he or she conducts a search; because of the uncertainty surrounding these parameters it is not clear that the firm will locate or organize the best possible technology as a result.

According to Nelson and Winter, most technological regimes are characterized by ‘natural trajectories,’ paths which technicians believe to be feasible and worth attempting (1982:258). These trajectories compose a few routes which direct R&D, since they seem to be the most logical and promising ways to lower costs or to create attractive new products.

2.1.1.5 Dosi

Anderson emphasis the role of the dominant design in establishing trajectories and especially argues that dominant designs arise because organizations seek certainty in their search patterns (Anderson 1988:39). This idea of dominant design is according to Anderson akin to Dosi’s (1982) argument that technological trajectories are shaped by ‘technological paradigms.’ Dosi defines a technological paradigm as “a model and pattern of solution of selected technological problems based on selected principles derived from natural sciences and on selected material technologies” (Dosi 1982:152). A technological trajectory is a pattern of “normal problem solving activity… on the ground of a technological paradigm” (ibid., 1982:152). According to Dosi, technological paradigms emerge for a variety of reasons, often institutional and/or political rather than technological (ibid., 1982:155). Dosi stresses that there is probably more uncertainty at the early stages of an industry’s history and more firms are gambling on different technological paradigms; “competition does not occur between the ‘new’ technology and the ‘old’ one which it tends to substitute but also among alternative ‘new’ technological approaches” (ibid., 1982:155). Anderson refers technological paradigm to dominant design and technological trajectory to the incremental change process.

2.1.2 The Elements of Anderson’s Technological Cycle

This section describes the elements of Anderson’s technological change. His definitions of the key concepts are included in this section as was mentioned earlier. Technology is defined according to Rosenberg (1972) as those tools, devices, and knowledge that mediate between inputs and outputs (process technology) and/or that create new products or services (product technology). The social, managerial and technologies other than product and equipment technologies are left out of Anderson’s work (Anderson 1988:14) and also of the present study. Moreover, in this study technology refers only to process technology. Anderson defines technological change as an event which lowers the production cost or improves the performance of an industry’s output by substituting a technically superior product or process for its predecessor. Anderson refers to Nicholson (1987) and says that the movements along the production functions (isoquants) in either dimension are not technological changes.

Technological innovation is defined as the first commercial introduction of a product or a process in an industry when that introduction constitutes a technological change as defined above (Anderson 1988:17). According to Anderson, his dominant design model relies heavily on the concept of technological discontinuity (1988:17). The discontinuity between major and minor innovations is common, but the basis of the distinction often varies from study to study. Arrow (1962), for instance, defines a major innovation as one which pulls the prices of a product below its previous perfectly competitive price; a minor innovation is one which does not. According to Anderson, Arrow's definition ignores the performance dimension and does not differentiate innovations which affect the competitive price a great deal from those which reduce it by a small amount (Anderson 1988:18).

According to Anderson (1988), to identify a technological discontinuity one has to be able to track progress in key performance parameters over time. In the flat glass industry (Anderson, 1988:105–106) output is essentially a commodity, and since scale economies are important, the key determinant (or performance parameters/dimensions of merit) of production cost is the output per unit of time of the most productive process equipment in existence. In plate and window glass, this was the square feet per hour capacity of a flat glass forming machine.

It is also evident that technological discontinuities are not all alike. Tushman and Anderson (1986) characterized technological discontinuities as competence-enhancing or competence-destroying. On the one hand, competence-enhancing discontinuities significantly advance the state of the art yet build on, or permit the transfer of, existing know-how and knowledge. Competence-destroying discontinuities, on the other hand, significantly advance the technological frontier, but with a knowledge, skill and competence base that is inconsistent with prior know-how. Competence-destroying discontinuities are so fundamentally different from previously dominant technologies that the skills and the knowledge base required to operate the core technology shift. The older technology quite seldom vanishes quietly; competition between old and new technologies is fierce (Foster 1986). That kind of major changes in skills, competence, and production processes are associated with major changes in the distribution of power and control within firms and industries (Chandler 1977).

In Anderson's study (1988:21) the industry is defined by Standard Industrial Classification (SIC) codes. In the statistics of this study, the industry is defined by SIC codes or by Customs Co-operation Council Nomenclature (CCCN) codes. Since these definitions set strict borders for industries, other types of qualitative measures are used to determine the links between the industries. This is an essential factor in this study since the value added products have a significant impact on the diffusion of new technology for the base product.

In Anderson's model a discontinuous technological innovation (see Technological Discontinuity 1 in Fig. 2.1) initiates a series of cycles which create a pattern of technological change in an industry. The usual course of technical progress in an industry consists of long periods of incremental change. A technological discontinuity arises, interrupts the era of incremental change and starts

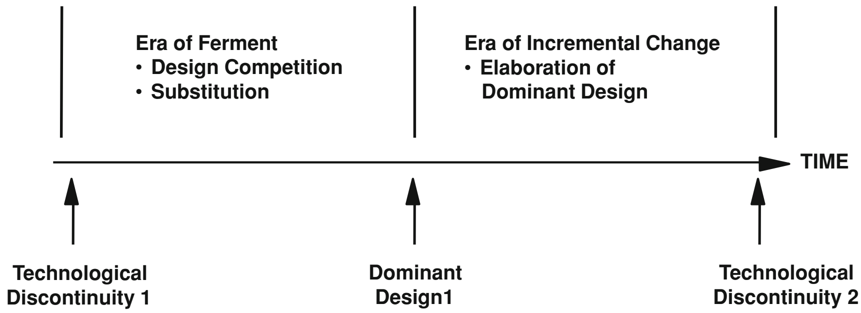

Fig. 2.1 The technology cycle (Reproduced from Anderson and Tushman 1990)

one of ferment at random intervals. Technological discontinuities initiate substantial technological rivalry between alternative regimes. Social, political and organizational dynamics select single industry standards or dominant design from among technological opportunities.

The emergence of dominant design ends the era of ferment and starts another era of incremental change, which is again interrupted by a new technological breakthrough. Anderson and Tushman argue (1990:606) that a breakthrough innovation inaugurates an era of ferment in which competition among variations of the original breakthrough culminates in the selection of a single dominant configuration of the new technology. Successful variations are preserved by the incremental evolution of this standard design until a new discontinuous technological change initiates a new cycle of variation, selection and retention. The cyclical model of technological change with its elements (i.e. era of ferment, dominant design and era of incremental change) is illustrated in Fig. 2.1. The elements are discussed below in greater depth.

Era of Ferment. The era of ferment is characterized by two processes. The first is technological substitution; the innovative product or process replaces the prior technical regime of the industry. The second is design competition. This period of substantial product class variation and, in turn, uncertainty, ends with the emergence of a dominant design. While dominant designs are critical at the process or product class level, for a given company, betting on a particular industry standard or technology involves substantial risk (Anderson and Tushman, 1990). An operational definition of the length of the era of ferment is that period starting with the year in which a discontinuous innovation commercially appeared on the market and including the first of the three consecutive years in which a design is applied in 50 % share of the new installations (Anderson 1988:108) see also the operational definition of dominant design below).

Dominant design. Finally, the era of ferment ends with the appearance and the predominance of a single design. Ultimately, one basic implementation of the technical breakthrough predominates and eliminates rival designs, for both technical and organizational reasons (Anderson 1988:44). On the technical side, a dominant design combines small advances into an effective combination. As the dominant design becomes the focus of R&D effort, one improvement leads to another and the dominant design becomes technically superior to its rivals. When the production volumes become higher learning by both doing and using takes place, thus lowering the production costs below those of competing designs (Anderson 1988:44). On the organizational side, the companies are driven to seek and adopt a technological standard. They try to avoid uncertainty (March and Simon 1958), and seek rationality, particularly in the technical core (Thompson 1967). The dominance of a substitute product, a substitute process, or a dominant design is a function of technological, market, legal and social factors that cannot be fully known in advance (Anderson and Tushman 1990). The operational definition (Anderson 1988:107) for a dominant design is a single configuration or narrow range of configurations that accounted for at least 50 % of the new process installations or new products in at least three consecutive years following a discontinuity.

Era of Incremental change. The emergence of a dominant design changes the competitive landscape (Utterback and Abernathy 1975). After a dominant design emerges, technological progress is driven by numerous incremental innovations (Myers and Marquis 1969 in Anderson and Tushman 1990). Variation now takes the form of elaborating the retained dominant design instead of challenging the industry standard with new, rival architectures. The focus of competition shifts from higher performance to lower cost and to differentiation via minor design variations and strategic positioning tactics (Porter 1985). The era of incremental change is characterized by incremental, competence-enhancing, puzzle-solving actions of many organizations that are learning by doing (Anderson and Tushman 1990:606). The cyclical model of technological change or the technology cycle is illustrated in Fig. 2.1.

2.2 Summary of the Literature

This section briefly summarizes the most important aspects of the concept, which will be evaluated. First, the operationalization (i.e. the definitions of the concepts) of the model is discussed. As was mentioned earlier (Sect. 1.2, p. 11), the definition of performance parameter in Anderson's (1988) study seemed to be weak. Anderson's performance parameter for sheet glass, plate glass and cement manufacturers measures the efficiency of an organization instead of its effectiveness (Pfeffer and Salancik 1978). Moreover, for some reason Anderson did not regard float glass as the dominant design although float glass is regarded as one of the most elegant innovations of this century (Caulkin 1987; Arbose 1986). It seems that operationalization of the model is the weakest point in Anderson's model and in his testing of the hypotheses. These will be discussed thoroughly in Chap. 5.

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