1 On the Origin of Products

1.1 Introduction

According to Grove (1997), human history has evolved through four stages. The oldest stage was that of the hunter-gatherer. About 7000 BC, the second stage, that of agriculture, began. New stages are usually enabled by new tools and/or knowledge, in this case, the tools and knowledge to cultivate the land. The third stage began with the Industrial Revolution around 1770 in England with the first textile mills. The fourth and last stage is the Information Age that began with the first computer in 1946. Perez (2002), however, sees the Industrial Revolution as the beginning of five periods of technological revolutions of about 50 years that correspond with the "long waves" of Kondratiev (1922, 2004). The five technological revolutions are the following:

– The Industrial Revolution (ca. 1770)
– The Age of Steam and Railways (1829)
– The Age of Steel, Electricity, and Heavy Engineering (1875)
– The Age of Oil, the Automobile, and Mass Production (1908)
– The Age of Information and Telecommunication (1971)

Within each "long wave," both Kondratiev and Perez distinguish four stages. Kondratiev distinguishes Recession, Depression, Improvement, and Prosperity; Perez distinguishes Irruption, Frenzy, Synergy, and Maturity.

The first phase – Irruption/Recession – begins with the results of the key technologies of the new "long wave." These results are improved; they attract new investors and companies. Existing companies that ignore the emerging technologies, or that manufacture products that become redundant because of the new technologies, get into trouble. This may result in increasing unemployment and will lead to a recession.

The Frenzy phase – or Depression – marks the time when some people make and some people lose a lot of money. Many individuals and companies invest in the new technologies and the supply of new products is very diverse; some of them succeed, a lot of them fail.

The turning point begins when dominant designs manifest. Perez calls this stage Synergy; Kondratiev called it Improvement.

In the final stage – Maturity/Prosperity – product development shifts from product improvement to production improvement. This stage will last until a new technology emerges and starts to threaten the existing products.

1.2 How Revolutionary Is Revolutionary Really?

In many publications (among others Schumpeter, 1939; Dosi, 1982, and Section 10.13 of this volume; Anderson and Tushman, 1990, and Section 10.3 of this volume; Christensen, 1997, and Section 10.10 of this volume), it is suggested that technology proceeds in two different ways: incremental development of existing products or processes, or discontinuous leaps caused by the invention of new (technological) possibilities. Rosenbloom (2010) and Rosenberg (1996) however argue that the immediate impact of these "discontinuous leaps" is shortly after their introduction rather small.

> Indeed few if any of the innovations we would characterize today as revolutionary appeared so momentous at the time they were first introduced.
>
> (Rosenberg, 1996 as cited by Rosenbloom, 2010, p. 11)

The explanations they give are that new technologies are often rather primitive at the moment of their introduction. They mostly perform quite poorly and in many cases, it takes a long time before their performance is good enough to become a threat to existing products. Another limiting factor of the success of new technologies is the interdependence of different technologies. The substitution of black-and-white by color TVs was only worthwhile after enough of the broadcasted programs were also in color. Rosenbloom and Rosenberg conclude that determining whether a development was revolutionary is most of the time only possible afterward.

Hybs and Gero state that the process that a designer goes through when developing a product is nothing more than:

> Selection, refinement, modification and combination of existing designs or objects considering the current performance requirements and constraints . . . It assumes an intrinsic evolutionary process in design, where any novelty, even a so-called innovative or creative design, is a result of recursive steps of generation and evaluation, and where each new solution is based on pre-existing solutions.
>
> (1992, p. 274)

In an afterword in his revised edition of *The Evolution of Designs*, Steadman (1979, revised edition 2008) writes – paraphrasing Basalla (1988) – with regard to the opinion of the general public that many innovations are revolutionary:

> There are always precedents according to Basalla for these apparent radical novelties. The general public only believes otherwise because the crucial antecedents have been lost or hidden, because technological change is confused with socioeconomic change, and because nineteenth century biographies of inventors depicted them as lonely heroic figures conjuring new machines entirely out of the air. (2008, p. 264)

1.3 Innovation

Innovation is generally defined as a process of introducing new products, processes, or technologies to better meet existing, new, or unarticulated needs. Innovation is regarded as the key to advancement and economic prosperity. As such it receives much attention.

This book addresses the following questions:

- How do new products come about?
- How do new products typically develop through time?
- How does the development of technologies and products relate to the context?
- How can designers apply evolutionary strategies?

1.4 Patterns and Mechanisms of Innovation

Many authors have discussed patterns and mechanisms of innovation and provided analytical tools to investigate them (Schumpeter, 1939; Rogers, 1962, 1995, and Section 10.25 of this volume; Abernathy and Utterback, 1975, and Section 10.1 of this volume; Dosi, 1982; David, 1985, and Section 10.12 of this volume; Anderson and Tushman, 1990; Von Hippel, 2005). Evolutionary metaphors have been used by several authors in this context (Nelson and Winter, 1982; Mokyr, 1996; Geels, 2002, and Section 10.16 of this volume). This book expands on this work, originating from a wide range of disciplines such as economics, sociology, science policy, innovation studies, evolutionary models, industrial design engineering, and design methodology, with the aim being to extend the descriptive and predictive power of the evolutionary paradigm as applied to technological innovation in general and the emergence of new (types of) products in particular. The next section summarizes major perspectives and conceptual models used to describe patterns and mechanisms of innovation that fit the chosen perspective.

1.4.1 Economics

Creative Destruction

Being key to economic advancement, innovation is the subject of the study of economics. The observation by Schumpeter (1942) that innovation is associated with creative destruction is a well-known comment. When new products, processes, or technologies are introduced that outperform earlier versions, the incumbent is ousted. The creative force of innovation destroys that which it improves upon.

Neoclassical economic theory assumes that the behavior of actors is based on relations between supply-and-demand and so sets prices for goods. It assumes stable prices once supply-and-demand are in equilibrium. However, it went not unnoticed that the economic process is a dynamic process and that innovations disturb equilibriums.

Nelson and Winter (1982) developed an evolutionary theory of economic change, which they based on continuous change to overcome limitations in conventional neoclassical economics that do not well explain the economic process of change or renewal. Instead, evolutionary economics describes the process of change along trajectories, based on the argument that economies grow because they are fueled by technical advancement. Nelson and Winter refer to all regular and predictable behavioral patterns within firms as “routines.” Put simply, the term “routines” encompasses all “know-how” and “know-what” those firms apply in their processes, and these can range from hiring personnel to research and development. Firms compete on the basis of the fitness of their routines that evolve over time, based on the premise of continuous change.

The economic historian Mokyr (1996, 1998, 1999, 2000a, 2000b) proposed an evolutionary theory of technological change, according to which it is more useful to analyze the change in techniques rather than the change in the artefacts based on those techniques. The argument provided is that a lot of techniques do not involve artefacts and that a lot of artefacts only acquire meaning once “how-to” instructions are included.

Path Dependence and Lock-In

Path dependence is a concept used to explain how a certain state, for example the design of a product, is explained by the preceding course of events. A broad and generic interpretation of path dependence is that “history matters.” However, this is regarded as trivial. A narrower interpretation of the concept holds that small events are a disproportionate cause of later events.

By its theoretical definition, path dependence has implications for the evolution of products. It is used to argue how a historical course of events can explain the outcome of a particular development. This course of events leads to a certain outcome, which is not a predefined equilibrium. A different course of events leads to a different outcome. It also suggests that a design that becomes dominant is not necessarily superior to other possible designs. Instead, small events in the course of history can make certain designs more viable in a market, which leads to self-reinforcing mechanisms that provide it with a continuing dominance, or lock-in. Based on this reasoning, the potentially superior design cannot develop sufficient momentum, or is locked out from the market, and therefore becomes unviable. The evolutionary race continues along the "lock-in" path until a next dominant design is set. In retrospect, the moments at which these paths are defined become important nodes in the evolution of products.

The concept of path dependence was developed by economists to explain how technology adoption and evolution of industries take place. Since then, the concept has also been applied to other fields. David (1985, and Section 10.12 of this volume) described path dependence in his iconic paper on QWERTY. Since then, QWERTY has been adopted as the paradigm case of path dependence. David argues in his paper how this particular keyboard layout became dominant in the course of time. Although the case and the arguments used are criticized by authors who distinguish different types of path dependence (Liebowitz and Margolis, 1990), the idea that development processes are path dependent is commonly accepted. The QWERTY case became one of the most influential articles in social sciences and developed into a polemic. Kay argues that if one would rerun the tape of history, QWERTY would always win. Basic probability theory is used to showcase that "the probability that the seven letters that make up 'typewriter' could finish up on the top row by chance is one in 5000" (Kay, 2013, p. 1177). In plain English, it is highly probable that these letters were arranged this way on purpose in order to allow salesmen to impress potential customers with rapidly typing the word "typewriter." Further, probability arguments are provided that the Dvorak Simplified Keyboard (DSK) layout has letter pairs prone to jamming that appear 16 times more frequently than in QWERTY. Hence, this layout would not have outcompeted QWERTY if it would have been around in the beginning of the typewriter evolution. Kay argues that DSK did not win the competition over QWERTY because it is inferior. Besides, DSK was patented 69 years after Christopher Latam Soles patented QWERTY in 1867 in the United States. And Soles was not the only one working on typewriters. In 1864, carpenter Peter Mitterhofer from Austria made the first typewriter from wood. In 1865, Rasmus Malling-Hansen from Denmark invented the writing ball, a typewriter with the keys placed on a sphere. The apparatus used a battery-activated escapement (Robert and Weil, 2016).

Another reflection on the topic of path dependence by Vergne (2013) argues that the theoretical concept itself is not to be disputed, but empirical evidence for path dependence cannot be provided by *ex post* case studies like that of David. For the record, Vergne notes that David did not claim evidence of path dependence, but described QWERTY as a rather intriguing case, believing many more similar cases to be around, which we do not fully perceive or understand. Vergne argues that as with most case study research, path dependence theory is not falsifiable. To illustrate his point, Vergne provides an overview of different research methods including simulation and laboratory experiments, and evaluates their strengths and weaknesses. He closes with a remark that scholars have done a poor job in empirically exploring path dependence. Better research is required, or else the concept remains as a trendy catchall phrase to explain virtually every sequence of events where history seems to matter.

Although QWERTY has become the dominant design for Latin alphabet typewriters and computer keyboards, some countries use variants adapted better to language specifics. In Germany and much of Central Europe, the QWERTZ variant is used. In the German language, the Z is more commonly used than the Y, hence their positions are switched. In France and Belgium, the AZERTY layout is the dominant design for typewriters and keyboards. In addition to a slightly modified sequence of letters, the localized layouts include language-specific characters like ä, ö, and ü (QWERTZ) and ç, à, é, and è (AZERTY). Anyone in doubt of the strength of the "lock-in" is advised to try a variant other than the one he or she uses daily. It is a frustrating experience.

A well-known, more recent example of path dependence is the triumph of VHS over other videotape formats. The VHS format was not superior to Betamax. On the contrary. The greater availability of VHS tapes compelled consumers to buy matching equipment. This network effect reinforced itself and eventually led to a win for VHS. Standards or standardization are often associated with path dependence. Standards can be coordinated through agreements set by industry bodies, as was the case with JPEG, which was defined as the file format for compressed digital pictures by the Joint Photographic Experts Group. In other cases, standards are set as the outcome of development processes, as was argued to be the case for the QWERTY keyboard layout.

Standardization defines compatibility between various products and users who use the particular standard. It shifts the locus of the evolutionary battle from the interface design defined by the standard toward application of the particular standard. It is not so much the technical superiority of a particular standard at a certain point in time that defines its evolutionary fitness. Rather, the versatility of use of the standard greatly influences the extent to which it is used, and so its economic success and with it, its evolutionary faith. An example of such a battle of standards can be witnessed at time of writing between standards for interfaces used for data communication and connectors.

FireWire, also known as the IEEE1394 standard, was developed by Apple in the late 1980s and early 1990s and first used in products in 1999. USB (Universal Serial Bus), developed in the mid-1990s by a partnership of companies, became quickly more used than FireWire. Both standards evolved through various versions that competed on the bandwidth of data possible to communicate with them as well as their versatility of use. USB replaced a variety of earlier interfaces such as serial and parallel ports, as well as power chargers. USB acquired a greater market share, and a larger diversity of types of use. FireWire declined in use, and Apple replaced it with the Thunderbolt interface in 2013. The evolutionary race continues with new versions of standards being released every few years. USB released a power delivery (PD) specification in 2012 that enables up to 100 Watts to be provided, where as few as 10 Watts was previously possible, with the intention of bringing about uniform charging of electronic devices. Based on this new specification, an interface named USB Type-C was developed, which prompted Apple to remove the connector used only for power delivery in its laptops released in 2015. Chances are these new standards will open evolutionary paths to many new types of use and new types of products not viable before.

1.4.2 Sociology

Diffusion of Innovation

One of the best-known models on innovation was developed by Rogers (1995, and Section 10.25 of this volume) and describes how new products, methods, or technologies diffuse through a population. In his book, of which the first edition was published in 1962, Rogers characterizes users according to their degree of willingness to adopt innovations. Those users most eager to adopt particular innovations are named innovators. They are followed by the early adopters, the early majority, and the late majority. Those users most skeptical and waiting to adopt innovations are called laggards. The definitions coined by Rogers are commonly used in popular culture and became a staple in marketing literature.

Rogers attributes five key characteristics that influence why potential adopters will consider using the innovation:

- Relative advantage, the advantage the innovation has over existing products.
- Compatibility, the compatibility with existing values, experiences, and needs of potential users. This is reminiscent of the Most Advanced Yet Acceptable (MAYA) principle of Raymond Loewy from the early 1950s (Loewy, 2011).

- Complexity, perceived ease of understanding and use.
- Trial ability, the degree to which the innovation can be tried (first-hand experience).
- Observability, the easier it is for potential users to see the result of the innovation, the better the chances are that it will be adopted.

The characteristics are all rather rational; however, aspects such as emotional benefits, habits, or status are not taken into consideration.

Over time, several theories of why consumers adapt an innovation have been developed. Ajzen and Fishbein (1980) introduced the Theory of Reasoned Action (TRA). Key in the TRA model is the postulation that behavior is driven by behavioral intention, which is a function of the person's attitude toward the behavior and a subjective norm, which is defined by the perception of whether people in the social network will approve the behavior. A limitation of the model is the assumption that an individual is free to act without any constraints. In reality, the intention to act can be restrained in many ways. Time, contextual limitations, existing habits, and abilities can and will limit a user in his or her feasibility to act. For instance, age-related functional loss will limit elderly users in their ability to act freely, as it limits their possibilities. The same limitations apply to the Technology Acceptance Model (TAM) proposed by Davis (1989) and Bagozzi, Davis, and Warshaw (1992). TAM tries to describe an individual's intention to accept and use a technology. In this theory, perceived usefulness and perceived ease of use determine the user's intention to actually use the technology (or the innovation using the technology).

Venkatesh and colleagues (2003) have tried to improve the Technology Acceptance Model. In their Unified Theory of Acceptance and Use of Technology (UTAUT), they describe four determinants for the use intention of the new technology and four influencers that describe the impact of the new technology. The determinants are performance expectancy, effort expectancy, social influence, and facilitating conditions. The influencers are gender, age, experience, and voluntariness of use. In contrast to TRA, TAM and UTAUT, the Lazy User Model (LUM) of Collan and Tétard (2007) aims to explain how a consumer selects a product from a set of possible, available solutions. LUM states that users will select the solution that fulfills their needs with the least effort.

All the mentioned models help to explain how decision making may be influenced, but lack explanations on how "effort" is to be understood, or how the different factors influencing the user's decision have to be weighed against one another, and therefore they do not answer the question how to use the models in a design process.

Social Construction of Technology

Another influential sociological perspective on innovation, referred to as the Social Construct of Technology (SCOT), argues *that technology does not determine human action, but that rather, human action shapes technology*. SCOT (Pinch and Bijker, 1984; Bijker, Hughes, and Pinch, 1987) takes us away from the common technology-centric view and underlines the forming pressures different social groups exert on innovating products and technologies. Bijker (1997) uses the SCOT perspective to describe among others how fluorescent lamp technology emerged and competed with incandescent bulbs. Fluorescent lamps were from the outset superior in efficacy terms. However, this appeared not to be sufficient to oust the incumbent incandescent lamps. According to Bijker, the struggle was not so much over pure technical benefits for the end user. Rather, Bijker argues, it was literally the power struggle between social groups that shaped the evolution of fluorescent lighting. Utilities that produced electricity wanted to further grow their revenue stream and rejected energy-saving technologies. Lamp manufacturers who competed among each other for market dominance feared losing market share and needed to cooperate with fixture manufacturers. Consumers were not a strong voice in this game. Hence, according to Bijker, we need to understand how social groups such as producers of electricity, manufacturers of lamps, and users interact to comprehend how in this case fluorescent light came about (see also Chapter 7).

From “Commodity” to “Experience”

In their book *The Experience Economy*, Pine and Gilmore (1999, and Section 10.23 of this volume) distinguish between the following four phases for products and services: Commodity, Good, Service, Experience. According to them, “Commodities” are taken from raw and basic materials. They are very similar, and that makes price the main means of competition. As an example they refer to coffee beans. If a company burns, grinds, and packages coffee beans, it makes what Pine and Gilmore call a “good.” Although the company can demand a better price than if it only sold burned coffee beans, the level of competition means its price cannot be set very high. “Services” are aimed at individuals. Service products use goods to create services for their clients. According to Pine and Gilmore, people are more interested in services than in goods and are therefore willing to pay more for them. They call the fourth level “experience.” Companies that offer an “experience” use their products and services to commit the customer. They explain: it is the memory that makes an experience stand out.

Designing Pleasurable Products

A model that is comparable to that of Pine and Gilmour is described by Jordan (2000, and Section 10.18 of this volume). According to Jordan, features such as the usability of a product start as – what in marketing terminology is referred to as – satisfiers. Later, however, they come to be expected, and this transforms them into dissatisfiers, in the meaning that they become dissatisfiers of the product if they are not a feature of it. He identifies three hierarchical levels of human factors: Functionality, Usability, Pleasure. Each level is a satisfier until most of the products have reached a certain quality. From that moment on, the lack of enough functionality or usability causes them to become dissatisfiers.

1.4.3 Innovation Studies

Sources of Innovation

Drucker (1985) argues that there are seven "sources of innovation": unexpected occurrences, incongruities, process needs, industry and market changes, demographic shifts, changes in perception, and new knowledge.

1 UNEXPECTED OCCURRENCES Companies should always consider that political, economic, social or technical occurrences can influence the requirements with regard to their products or services and can offer opportunities for innovations. An example, described in further detail in Chapter 8, is a car accident in 1994, when three-year-old Dana Hutchinson was killed after being struck by an airbag deployed while in a rearward-facing child seat in the passenger seat. This resulted in legislation changes that made warning labels on child seats and airbag cut-off switches for cars obligatory.

2 INCONGRUITIES An example of incongruity is when a company is trying to solve the wrong problem. Drucker describes the incongruity in development of new ships in the ship-building industry. For many years, the involved parties tried to reduce fuel consumption and improve the speed of the ships to save on costs without much result, until they discovered that most costs were made when the ships were in the harbor for loading and unloading. Once they understood where the costs lay, the solution was obvious: the roll-on and roll-off ship and the container ship – solutions that had been in use on trains and trucks for many years.

3 PROCESS NEEDS This concerns products that are needed to make a process go (more) smoothly. The world is full of them: a mobile phone frees you from a wire, a car navigation system makes it possible to find your way in unknown areas even when driving alone, which used to be quite dangerous in the times when you needed to read a map while trying to drive safely.