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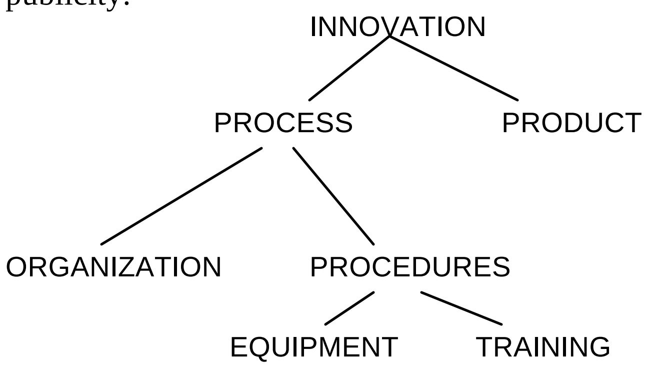
TECHNOLOGICAL CHANGE
PART II: INNOVATION AND DIFFUSION

"*Woe to him who innovates without regard*" Tao-te-Ching

Innovation.

In the introduction to "Technological Change: Part I", I described Schumpeter's concept of the role of the entrepreneur in selecting, from the set of feasible inventions, those to be developed for the marketplace. I pointed out that a modern interpretation would replace the simple linear model commonly assumed during the first half of this century with a more complicated "network of actors" model. Amongst the actors, with examples of the roles they have played in specific product innovations, we find product planners, designers, marketing experts, consumers --comprising "the Market"; regulators (example: breast implants); forecasters (who generate self-fulfilling prophecies); and pressure groups (example: advocates of phosphate free detergents which have their own negative impact on the environment)

The diagram is a simple typology of innovation. The importance of process innovations is often underestimated because they take place far away from the glare of publicity.



Organization

In general, changes in either the product or the process will entail changes in the organization. Production systems tend to be politically biased at the very least and this has a strong influence on the organization of the firm. For instance, mass-production using the transfer line entailed Taylorism and standardization. Organizational innovation to-day, using flexible manufacturing systems, involves the formation of teams and quality circles, the provision of new services (e.g. stress management facilities), and sophisticated computer-based management of inventories. I include in "organization" the culture of the workplace and in this aspect a revolution or paradigm shift appears to be taking place - although unevenly - from an authoritarian to a participatory model. This is not widely understood, or , if it is, the absolute dependence for its success on mutual trust is not comprehended (example: 1995 changes to labour laws in Ontario).

Change not the same as progress

Technological change is not always linked to social progress . For example, -- as shown in Winner's examples -- changes are sometimes made for reasons that have more to do with power than with productivity. This aspect of innovation is usually left out of account in economic studies.

Frivolity is the mother of innovation[1]

Technological growth occurs first in the areas of the superfluous, the useless, the gratuitous, the secondary. Example: Computer games versus affordable, energy-saving housing.

However, techniques developed for frivolous reasons may be transferred to more serious uses. Porcelain and glass were luxury goods before they were necessities. Metallurgy was first used for jewelry and only later for knives and axes. Light alloys now essential to aircraft were developed for tennis racquets and golf clubs[2]. On the other hand the wheeled toys of pre-Conquest MesoAmerica never gave rise to scaled-up wheeled vehicles[3]. Was this a social problem or did it reflect the mountainous terrain?

An excellent contemporary example of this phenomenon is the Digital Versatile Disc (DVD) to be launched in the Fall of 1996 as an entertainment product. A single disc will be able to hold one movie of 2 h 13 min duration on one side with up to 32 subtitle tracks and 3 audio tracks.[4] But the ultimate importance of this technology will lie outside the field of entertainment as a massive memory storage: in its read-only data format DVD will be able to hold entire libraries (4.7 Gbytes per side).

Depth of Change

Innovations may be classified according to the profundity of the technological change[5] that they entail. The following is my own schema selected from various authors.

Incremental innovations (kaizen, Verbesserungsinnovationen)
Radical Innovations (Abetti's: "breakthroughs in technology" others' "basic innovations"
Changes of `technology system' (Abetti's "Very complex systems")
Changes in the techno-economic paradigm. or "style" of the economy. (Also referred to as "pervasive generic technologies"[6]

Incremental Innovations

Incremental innovations (Japanese Kaizen) go on all the time. They do not arise as the result of any deliberate R&D but as the result of inventions and improvements made by engineers and those on the shop floor. They account for the vast majority of patents. According to Abetti, they have an average life of 5 a. New products have an average life of 10 a. Examples: electronic games (Fig. 95)

The dominance of incremental innovations explains, in my opinion, the Schmookler correlations (Fig. 134) between patents granted within a given industry and economic activity in that industry. Even R&D-based innovations will track production if a firm allocates its R&D budget as a fixed proportion of its expected sales. This is in fact common practice. The oil industry certainly operates this way, even though from the long-term point of view one would do just the opposite. But then the long-term view is not something with which business is comfortable.

Radical Innovations

Radical innovations are usually imposed on the market by unusual entrepreneurs according to Schumpeter. They may often involve a synergistic combination of product, process and organizational innovation. The MacDonald Restaurant Concept was a radical innovation with all these aspects. It has been called a "social technology"[7]

Evidence of market-led radical innovation is weaker than for incremental ones but "it is clear that the inventors do have a market in mind."[8]

The birth-control pill was a radical innovation with huge social and moral repercussions. The VCR had huge impacts not only on television but on the movie industry, on education and training, on domestic behaviour.

Systemic Change

Changes in the technology system are based on a combination of radical and incremental innovations together with organizational innovations <u>affecting more than one or a few firms</u>. A whole cluster or "constellation"[9] of innovations took place between 1930 and 1955 centered on synthetic materials like nylon and "plastics"; this included a wide variety of synthetic moulding and extrusion machinery. Ellul uses the word "ensemble" for such a cluster. This represented a systemic change in the techno-economic system.

I am not sure where to put the introduction of amateur photography. Its historian[10] described it as a complete technical system. It involves firms making cameras and lenses; retail stores and developing/printing firms; specialty magazines, social organizations and perhaps a whole change in attitude to memory.

It had profound effects on engraving, portrait painting and on professional photographic studios. It's a borderline case between radical and systemic.

Systems of manufacture associated with the names of Ford, Nissan and Toyota belong in this category. Taylorism, often known as "time and motion study", was a pervasive technology whose influence is still felt and which inspired the Soviet dictators (it is referred to in many places in Yevgeny Zemyatin's classic novel *We* (1920).

Techno-economic Paradigm Changes

Changes in the techno-economic paradigm or style have a major influence on the behaviour of the entire economy. These are the "creative gales of destruction" which have been claimed to assail the economy once every 50-70 years, thus giving rise to "Long Wave Theory" associated with name of N. D. Kondratiev. They are associated with pervasive generic technologies. The combination of innovations associated with the microprocessor is the most recent of these paradigm shifts. Its effect on process as opposed to product has yet to make its full impact. The ensemble of techniques connected with recombinant DNA may be the next technology to give rise to a paradigm shift.

Carlota Perez[11] refers to these as "changes in the technological style". Her analysis seems to me to be the most profound of all those offered for the so-called Long Waves or Kondratiev waves (Figure 132 "Key Factors and technological styles characteristic of Kondratiev waves"). Nevertheless, the theoretical basis of the long waves has been convincingly undermined by Tylecote[12] who has argued

(1) There is no regular long wave in the conventional economic sense of alternate fast and slow expansion of the world economy over an

(approximately) fifty-year cycle, except for the period since the 1930s - and some approximation to it in the fifty years before that.
(2) We have no reason to expect such a wave over the whole "industrial" period, because the "feedback processes" which might give rise to it -- which I argue have recently given rise to it -- were not, and could not possibly have been, sufficiently unchanging over 200 years.

MAJOR TECHNO-ECONOMIC PARADIGMS

Period	Description	Key factor	Rising industries
1770s to 1840s	Early mechanization	Cotton Pig Iron	Steam engines Machinery
1830s to 1890s	Steam power and railway	Coal Transport	Steel Electricity Gas Synthetic dyestuffs Heavy engineering
1880s to 1940s	Electrical and heavy engineering	Steel	Automobiles Aircraft Telecommunications Radio Aluminium Consumer durables Oil Plastics
1930s to 1990s	Fordist mass production	Energy	Computers TV NC machine tools Drugs Military technology
1980s to 2030	Post-industrial style	Microproces sors	Biotechnology

Fig 410 (Sources: Perez, Freeman, Fitzgerald-Moore)

Rate of Change

It is commonly accepted that the rate of innovation is getting faster. It may well be true that more novel consumer products reach the market each year. But the rate of innovation depends strongly on the level of change. I have strong reservations about the claim that radical innovations take a shorter time to incubate than they used to. Ellul agrees.[13]. One can make a selection to prove anything as was done by Bell Telephone many years ago (Fig. 395) This is especially easy if events are speeded up by a war, as was certainly the case with radar and atomic energy.

Incubation lasts from 20 to forty years and pretty well always has done.[14] DNA was discovered 40 years ago. Power Steering took 25 years to reach market (1926-1951) and that is certainly not radical. The Partnership for a New Generation of Vehicles (PNGV) has a twelve year timetable just to develop a prototype (by 2005)[15] which is the same time it took James Watt to develop his improvement of Newcomen's engine. The RandCorp report of 1965 concluded that the gap between discovery and application had remained practically the same from 1900 to 1965. In large civil aircraft the design and development periods are increasing[16]. The design definition phase of the Boeing 727 lasted 2.5 years; the same process for the 767 lasted nearly 6 years.

Case history

It took Merck almost 40 years to bring its cholesterol-control drug lovastatin to market. Research began in 1950s. Enzyme isolated in 1979. Clinical trials 1980. (Usual cancer scare stopped development in Sept. 1980). Canada's HPB (Health Protection Branch) approved June 1988.

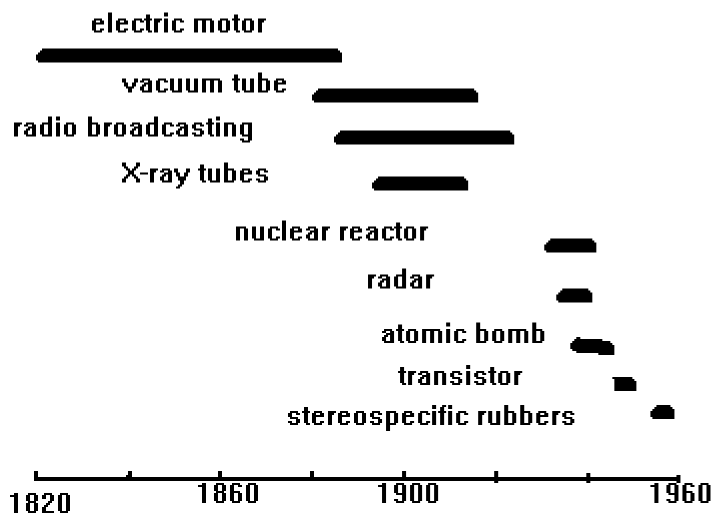
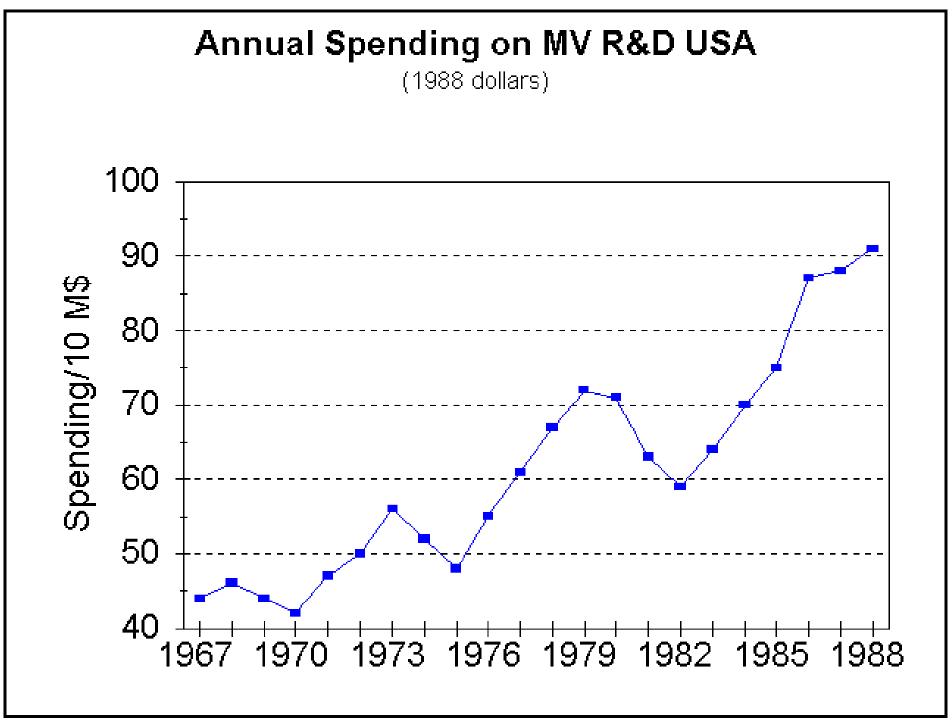


Fig.395 (Data from Bell Telephone Laboratories, Inc.
Interval between discovery and application in the physical sciences.

Regardless of time, there is no doubt that the **cost** of innovation is rising steadily or even exponentially. Fig.396 below is redrawn from data in OECD 1992, fig.2.

Because of long lead times the correlation between expenditure on research and rate of successful innovation is remarkably weak.

Factors for success



The most important predictor of success is a "superior product which offers unique benefits to the user".[17] (e.g. aluminum vs. steel rusty cans; telephone vs. telegraph.)

Not all new technologies have to battle for existence against an incumbent one. Advancing technology creates previously non-existent demands from consumers [Say's Law]. *Placement* artifacts create their own markets; the manufacturer may "place" them at or below cost to generate the demand. This is commonly done with new software (e.g. Netscape)

Replacement artifacts are improvements over existing ones. The improvement may be substantial and enlarge the market. Or it may be simply a substituting product that removes some disadvantage of the old one (unleaded fuel). The attacker has no advantage in this case.

The following internal requirements of success *within* the firm have been identified by one management school[18]: (Fig. 143) :

1. There must be an entrepreneurial team to sell the idea. and a "product champion" -- someone who wants the innovation to happen and is influential. One of the reasons given for the failure of the Aramis Personal Rapid Transit system was the lack of a product champion. M. Etienne, in conversation with Bruno Latour, said, "Aramis never had an engine....I mean a local engine, a driving force: a politician, an elected official, somebody with pull who would have made it his cause..."[19]

2. There must be free communication channels both inside and outside the firm. Technology is f their desks are 1 m apart it may be 100%. At 30 m it may have dropped to 10%. This conclusion, if substantiated, would obviously have profound implications for telecommunications.

Two important aspects of the process of innovation need special mention in this context: translation and negotiation.

Translation

Because the process of innovation involves many social groups -- scientists, technologists, entrepreneurs, bankers, government regulators and so forth -- chains of translations from one technical language to another are an essential part of the process. And, as always, "something is lost in the translation". The capabilities of the invention are naturally exaggerated by its champions. The scientific principles may not be understood by the lay actors.

Negotiation

The final form taken by the innovation is always a compromise between the often conflicting aims of the actors. At each stage in the development, therefore, negotiation takes places between the actors.

Success.

In addition to the **technical success**, the innovation must be a **commercial** success i.e. people must actually buy it. An example of a technical success that filled an apparent market gap was CORFAM on which Dupont spent 100M$. The American public refused to buy it. But this story has an interesting sequel, for the plant was sold to Poland where it was successful. This shows the importance of culture as a determinant. In fact it is one of the strongest case histories I have on the influence of societal culture on technology.

An important factor in commercial success may be the supply of **complementary products** - products required in order to use the innovation. Software is required to make a computer system marketable; it must be compatible with the system. CDs are required to make CD players marketable. One reason why VHS won out over Betamax was because there were more videos available in that format.

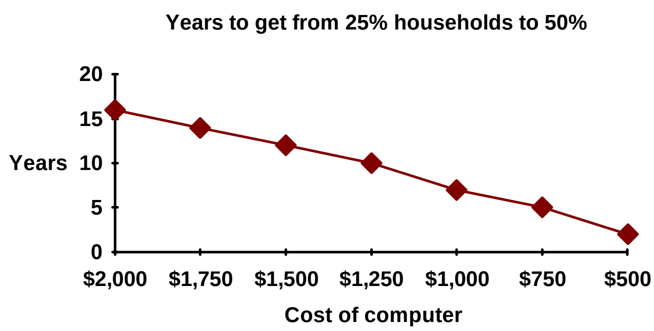
JVC, who developed the VHS standard, allowed others to use the VHS standard for a very low royalty. As VHS-compatible players proliferated, video rental stores tended to stock more VHS than Beta tapes. VHS was the beneficiary of a positive feedback cycle. But not at the expense of *quality*. Once VHS emerged as the apparent standard, about 1983, an *acceptance threshold* was crossed. It led to renting movies becoming one of the most popular forms of home entertainment.[20]

For major technological changes of a systemic nature a whole infrastructure may be necessary, involving both the private and the public sector: For example a highway network and a network of filling stations or electric recharging stations were required for the diffusion of the automobile. The "Information Superhighway" provides the necessary infrastructure for the new wired universe of the Internet. The Internet technology is still in technology push mode. But as content builds and opportunities for money-making are discovered, no doubt it will enter a demand pull phase.

Finally it must be a **financial success.** An example of failure was the heart pacemaker designed by General Electric. Although it met technical and commercial criteria, it was withdrawn on the advice of lawyers who feared lawsuits. In the light of recent experience with a breast implant, this may have been very wise. The growing importance of the **regulatory** environment has to be a major concern. But social health and safety; employment policy and environmental factors are beginning to be considered.

Too strong an emphasis on financial success tends to strangle innovation. A culture devoted to the short-term bottom line will not take the risks necessary to succeed. "[T]herein lies the story of [Britain's] gentle but remorseless fall down the international economic league tables."[21]

Diffusion



From the start of an innovation to the marketing of a product we now expect a delay of about four to seven years. When the innovation has been adopted and put on the market, it will diffuse both in area and market penetration over time. The proportion of the market penetrated plotted against time gives the characteristic "market penetration S-curve". For diffusion to pervade the global marketplace may take another 25 years. However, during this time we now expect to see constant feedback from the marketplace to generate improvements: these will clearly be demand-pulled. The effect of these developments on the trajectory of technological devices and systems is elaborated upon in the chapter "Trajectory". What is of immediate interest is the time taken to achieve certain benchmarks, such as 25% or 50% penetration.

Experience has shown that pricing is of key importance. Thus John Kettle[22] estimates that the time taken for computers to move from 25% penetration to 50% penetration will be 16 years for a machine costing $2000 but only two years for a machine priced at $500.

Review Questions

1. What are the four levels of technological change? Give one example from each of two levels.
2. What level of technological change is represented by the introduction of the pocket camera for amateurs; justify your choice.
3. Of the innovations introduced to the market during the last ten years, which do you think will most affect your quality of life?
4. How would you test the hypothesis that "innovation is speeding up"?

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[1]Innovation is limited by a strange phenomenon ascertained by Bertrand de Jouvenel (Arcadie; Paris SEDEIS, 1969 ?). "The crafts that have progressed the least were those that could have improved the material lot of the majority". And Tessier du Cos "The more an industry responds to basic needs the less it innovates".

[2](ref. to C.S.Smith, Prof. at MIT in 70s)

[3]Basalla p.10 (from Stuart Piggott, 1983)

[4]Advertising Supplement to *Globe and Mai*l 96 08 16 C2.

[5]Christopher Freeman

[6]Freeman 1987 The Challenge of New Technologies in Interdependence and Co-operation in tomorrow's World. Paris: OECD.

[7]Laurent Thibault of the Canadian Manufacturer's Association

[8]Freeman

[9]Keirstead

[10]Jenkins

[11]Perez, Carlota (1983) Structural change and assimilation of new technologies in the economic and social systems. *Futures*.

[12]Tylecote, Andrew (1992). *The long wave in the world economy: the present crisis in historical perspective*. London and New York: Routledge.

[13]p.287 "when we know about the plurality of Technological factors involved in any innovation, we have to ask ourselves when is the true point of departure"

[14]For Bell's estimate see diagram produced by William O. Baker in Ginzberg ed. Technology and Social Change p.87.
See also Edwin Mansfield, The economics of social change, p.100 et seq.

[15]Chemistry & Engineering Aug.1, 1994.

[16]OECD, *Technology and the economy*, 1992, ch.2.

[17]Research at McMaster (1990) by Bob Cooper and Elko Kleinschmidt called NewProd.

[18]Lecture by Prof. Abetti

[19]Bruno Latour (1996). Aramis or the Love of Technology. Translated by Catherine Porter. Cambridge MA: Harvard University Press. [Aramis is an acronym for Agencement en Rames Automatisées de Modules Indépendants dans les Stations.]

[20]Bill Gates (1995). *The road ahead*. p.46

[21]Will Hutton. *Manchester Guardian Weekly*, 23 June 1996, p.16.

[22]"What cheap computers would mean" Globe and Mail 7 June 1996 B9.