TECHNOLOGICAL SUBSTITUTION AND INDUSTRIAL CHANGE

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TECHNOLOGICAL SUBSTITUTION AND INDUSTRIAL CHANGE

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1. Diffusion among both buyers and sellers

The distinction between diffusion of the use of new products among buyers, and diffusion of competitive production among sellers is empirically important. The purpose of this paper is (a) to illustrate and model these two diffusion processes in one context and to be explicit about the linkages between the two processes. Furthermore (b) we elaborate the linkages between the processes of entry into, and exit out of a technology. This will be done first by presenting a few case illustrations.

The general idea is as follows. An innovation, in this paper typically a product innovation, will diffuse among a population of buyers (users), thereby possibly substituting an old product. This diffusion process is what has normally been modelled in previous research (see e.g. Mansfield 1968, Mansfield et al. 1977, Freeman et al. 1982, and Sharif and Ramanathan 1984. See, however, Metcalfe 1981 for a path-breaking exception). At the same time competitive production will also be taken up by other producers/sellers than the innovator, and the innovation will diffuse among a population of imitators (or close-to-imitators). To a certain extent this diffusion process, which involves entry into or switching to the new technology by a row of firms, will at the same time be accompanied by exits of firms that for some reason cannot or will not manage the new technology. That is, technological substitution may occur completely, while substitution of firms may occur only partially. Indeed, it is hypothesized in this paper that over the long run a series of technological substitutions will cause structural change in industry to a lesser and lesser degree due to a kind of "intergenerational" managerial learning how to handle these substitutions or product generation shifts. This is **not** to say that in the long run technological substitutions will be managed in large, existing firms while successful technology based entry by new firms will not, but that structural changes induced by technological changes will be increasingly smoothed, leaving less - but still perhaps significant - room for random-like events.

The two diffusion processes among buyers and sellers respectively, are of course interdependent, the nature of interdependence being both product and market specific. For example, if the diffusion among buyers is profitable and rapid, imitators will be attracted, and diffusion among sellers will speed up (unless patent protection slows it down). Similarly, rapid diffusion among sellers may strengthen marketing efforts and speed up the diffusion among buyers. The common factor behind the speed of diffusion is that the innovation generates an extra return over costs in both its use and in its production. However, the faster and more widespread the diffusion, the faster these extra returns tend to be competed away.

A slow seller diffusion may not necessarily slow down buyer diffusion unless capacity problems arise. If the innovator holds a strong patent and does not want to sell licenses, it is generally in his interest to promote buyer diffusion, while halting seller diffusion. If the innovator offers licenses, seller diffusion may be speeded up, not necessarily speeding up buyer diffusion. Also, a firm may sell licenses and thereby use a rapid seller diffusion as a means to increase buyer diffusion in order to outcompete alternative technologies. A case in point here is the licensing of JVC/Matsushita's VHS-technology for video cassette recorders, which finally almost outcompeted Sony and its Betamax-technology.

2. What happens with the new product and technology during the diffusion process?

The product and its technology continue to change and develop during its diffusion. At the buyer side adaptions to different users are made, new applications are found and new ideas come up, not seldom from the users themselves (von Hippel 1976 provides elaborate illustrations of this). At the seller side imitations are rarely true copies, but both modifications and significant changes occur as a result of adaptions to the different production equipments of the makers, inventions around the patents of others, product differentiation and new ideas (as illustrated by Rosenberg, 1976). Often such changes and developments during diffusion processes take the form of minor piecemeal improvements which cumulate, but also radical changes occur. Thus an innovation is never a one-shot affair, but it triggers a swarm of mostly minor changes, occurring partly as a result of diffusion. Hence, the common innovation/imitation dichotomy easily gets less useful for descriptive purposes.

Taken together the subsequent changes and innovations lead to mostly gradual increases, with some jumps in the technical performance of the product (now in a broad sense) along some of its performance parameters (weight, efficiency, durability etc.). These increases in performance are sometimes correlated with cumulative production as well as with the cumulative stock of products in use and thus can be interpreted as a result of learning - **learning by producing** and **learning by using** - as demonstrated by Sahal (1981). An important question relates to exactly what factors account for this learning, and whether learning takes place predominantly at the buyer or at the seller side at different points in time and who appropriates the benefits of learning. However, it may be argued that the really important point is not whether technological change, based on learning, is user driven or producer driven, but what makes the whole intra- and interorganizational system (or network) of actors function as a learning system. Technological change may take place among makers of materials, production machinery, components, and all kinds of suppliers as well as among users with different applications and among makers and users connected to the user environment.

3. What factors govern the buyer/seller-diffusion process?

Adoption decisions by users and imitation decisions by producers can be viewed as decisions to enter the new technology. Exit of an old technology is part of this process. These entry and exit decisions are largely governed by long-run profitability expectations both among buyers and sellers. These expectations are formed on the basis of many more factors than short-run price signals. The extra rent or profitability of the innovation among both producers/sellers and users/buyers can be represented by a difference (ε) between the rate of return on operating capital (R) and the interest rate (i) as described in Eliasson (1986), that is $\varepsilon = R - i$.

In this case the rent is defined at a lower aggregation level than the financial decision unit ("the division") introduced by Eliasson. Each innovation means an increase in the technical performance of the product, which represents an increase in the value to the buyer, in turn, using the product in his production process (as an intermediate good - a new material, a new component, a new piece of machinery, a new ancillary product and the like). The price of the new product distributes this value increase between the buyer and the seller. Thus, we can distinguish between two profitability measures, ε_B and ε_S for the buyer and seller respectively (cf. Metcalfe 1981).

Thus, for each product innovation ε's among individual buyers and sellers are generated during the corresponding diffusion of the innovation among buyers and sellers. While the ε's for an individual buyer essentially depend on the price and the product's technical performance (or price-performance ratio), the ε's for the innovator and the subsequent imitators depend on price, cost characteristics and the combined effects of the diffusion pattern among both buyers and sellers. Typically a high buyer-diffusion rate and a low seller-diffusion rate benefit the innovator. An efficient patent is sufficient to delay seller-diffusion but it is not a necessary condition.

Next two cases will be given which illustrate different effects of technological substitution on industrial structure.

4. Technological substitutions in the US sweetener industry

A sweetener has the function to give a sweet taste to food and drinks, at the same time as it may, or may not provide nutrition. Two outstanding innovations in the sweetener market since World War Two are High-Fructose Corn Syrup (HFCS) and aspertame (APM). HFCS is produced from corn by using a special enzyme, glucose isomerase, that enables the conversion of the monosaccharides glucose to fructose. HFCS is a natural, high-calorie sweetener, while APM is an artificial, low-calorie sweetener. The latter is based on the invention of a sweet compound of two non-sweet amino-acids.

Both HFCS and APM compete in large market segments with natural sugar produced from primarily sugar canes and beets. Soft drinks make up the most important market segment. In certain segments there is also competition from other artificial sweeteners such as saccharin, cyclamates (presently banned by FDA in the US) and acesulphame-K.

The diffusion processes of these two innovations differ significantly. Regarding HFCS, major discoveries of how to isomerize glucose into fructose were made in the US and Canada in the 1950s, outside the sweetener industry. The main part of the following R&D was then made in Japan in the 1960s, again outside the sweetener industry. The US sweetener industry, mainly consists of the corn wet milling industry and the sugar industry. It was late in entering into HFCS R&D, both because of slow diffusion of information into the industry and because of a slow industry response to the information. This is remarkable since the corn wet milling industry - the main beneficiary of HFCS - had for a long time been looking for a way to isomerize glucose to fructose.

Finally, Clinton Corn Processing Company in the US bought a license from Japan and began to test market HFCS in the US in 1967. Clinton also started to offer sub-licenses to other US corn wet millers. The response by these was slow and only one company, Staley, bought a sub-license. By 1972, HFCS technology was, in fact, within reach for all corn wet millers, but only two companies had built full scale plants.

On the buyer side, initially diffusion of HFCS was also slow. For the important soft drink market the first adopters were small regional softdrink companies. The large companies, such as Coca-Cola, were late in full adoption. Initially, the first HFCS producers had a hard time. A price hike for sugar in the mid 1970s speeded up buyer diffusion and the initial HFCS sellers had some very profitable years, until seller diffusion increased. Additional entries into the industry were made and existing companies increased their capacities. World sugar prices fell and rose again together with increasing HFCS capacity. However, high US sugar price levels were maintained by a US sugar support program, which significantly contributed to the overall diffusion of HFCS-technology. The sugar companies tried to enter HFCS in the late 1970s but had with no exception failed and exitted by 1985.

A second generation of HFCS, called HFCS 55% in contrast to the first generation called HFCS 42%, was developed in the late 1970s. In general this innovation diffused rapidly among both buyers and sellers without significantly rearranging competitive positions among sellers.

In the late 1980s it is expected that HFCS will reach market saturation levels in the major market segments - provided no new major HFCS innovation appears. HFCS in dry form would be such an innovation, since HFCS is currently distributed in liquid form and cannot compete with table-top sweeteners.

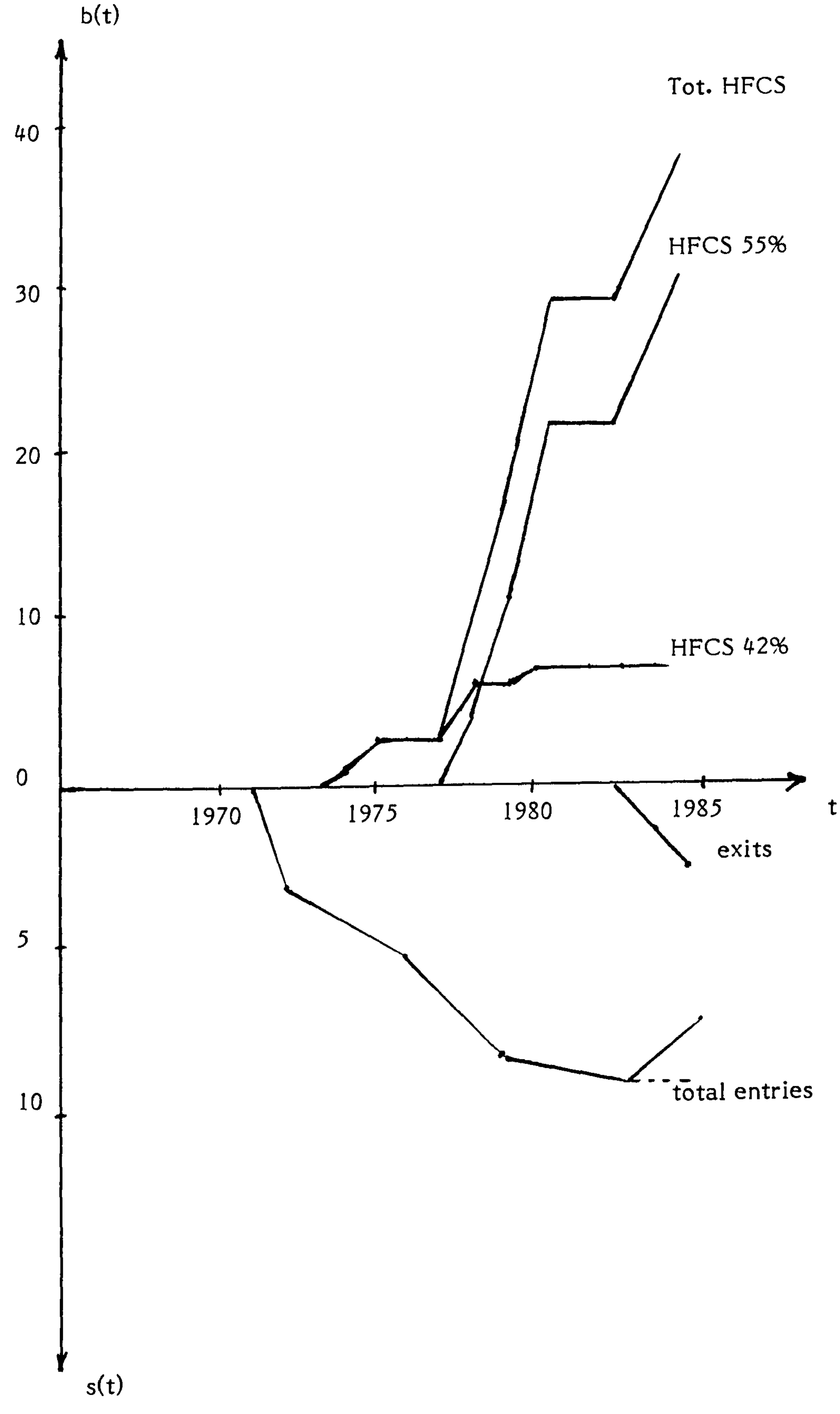
US demand for sweeteners has grown considerably, but because of HFCS substituting for sugar, there has virtually been no growth in sugar sales in the US market since 1975. Imports of sugar have decreased drastically, forcing some developing countries to more or less exit from the US market. The diffusion of HFCS thus also represents a case of import substitution, initially based on the acquisition of technology from Japan and then indirectly aided by protectionist measures aimed for the industry it competes with (sugar industry) on the domestic market.

Figure 1 shows the buyer diffusion pattern in the soft drink segment, adoption measured as at least 50% approval, together with seller diffusion, simply measured as the number of firms competing in the HFCS industry.

Aspertame (APM) was discovered in 1965 by a researcher at the US company Searle. (In fact, it was a typical serendipity). Searle did exploit it by in-house R&D, production and marketing but it took until the early 1980s before it finally got FDA approval and reached the market. It is yet too early to assess its probable market impact in the future, but so far it has diffused rapidly among buyers in certain segments, substituting for sugar, HFCS and saccharin. However, the seller diffusion has halted, since Searle maintains a strong patent protection and does not license. When patents start to expire in a few years, imitators are expected to make entries. Searle's strategy to meet this is by emphasizing process R&D and cutting cost, benefitting from dynamic economies of scale and more efficient processes. A price fall due to seller diffusion will speed up buyer diffusion, and it has even been suggested that APM will more or less outcompete HFCS and sugar in certain segments.

FIGURE 1

Buyer/Seller-Diffusion of HFCS in the US



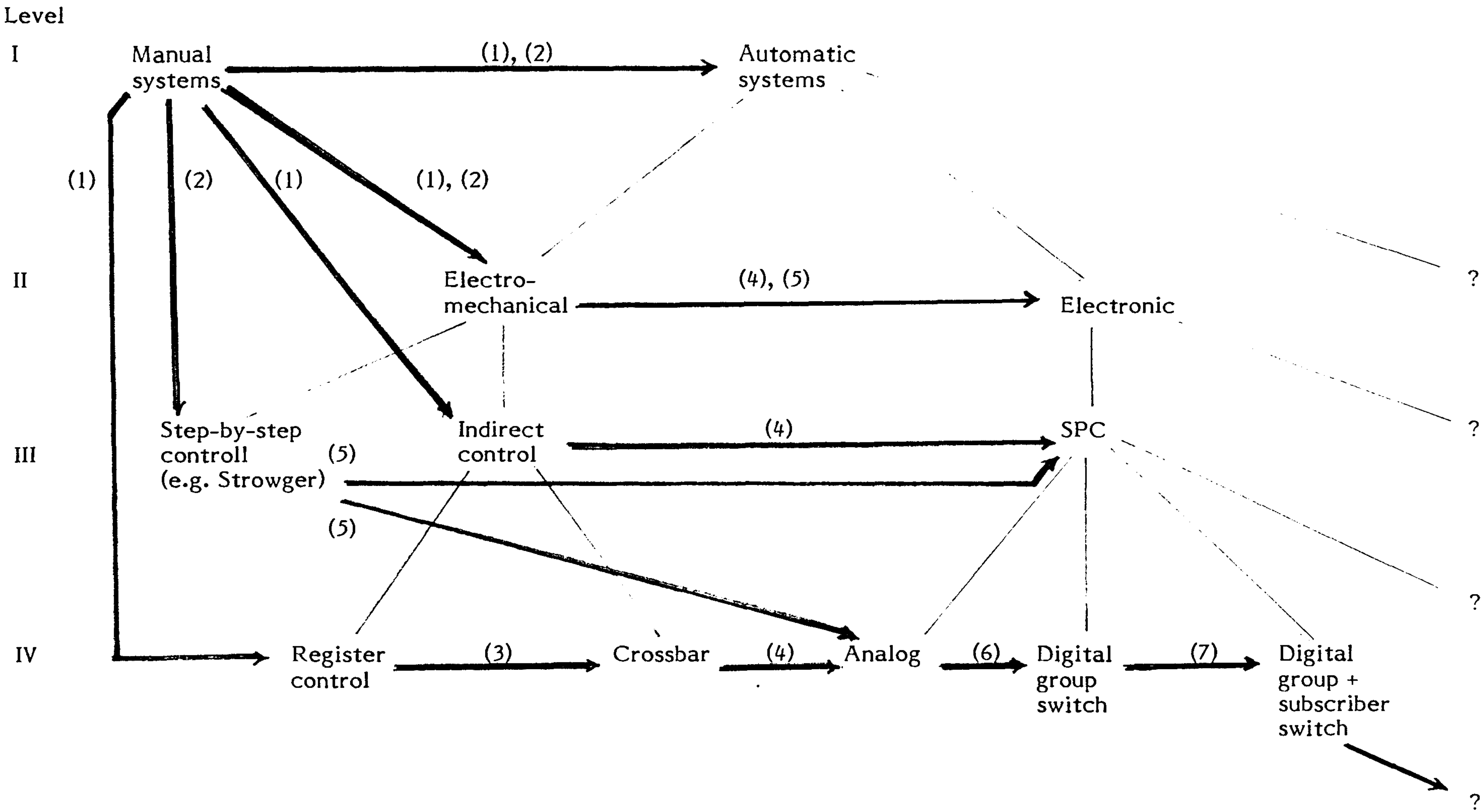
5. Technological substitutions in the telecommunications industry

A telecommunication network for speech, text, data and images consists of subscriber equipment (telephone, dataterminal etc.), transmission equipment (cable, radio, satellite) and switching equipment, which connects subscribers locally, regionally and internationally to "the world's largest machine". Technological changes in these three types of equipment occur with different pace in different periods. A core technology is switching technology. Figure 2 shows the main technological substitutions in this field. (The numbers indicate corresponding substitutions on different levels of classification.) Without going into detail one can observe that despite a number of radical technological changes during roughly the last 100 years, the industry has remained relatively stable, see Table 1. There have been few entries and few exits. In contrast to the sweetener case, technological changes have been absorbed by the industry without disrupting it too much, even in case the major sources of innovation were largely outside the industry as with stored program control (SPC).

The diffusion of SPC-technology also provide a good case illustration of interdependence between buyer and seller diffusion. The three main pioneers in the export markets for telephone switches based on SPC were CIT-Alcatel (France), Ericsson (Sweden) and Northern Telecom (Canada). The marketing efforts of these companies speeded up the recognition and final "switching" to SPC-technology among telephone service companies worldwide. During a short period of some years in the 1970s the buyers of telephone exchanges shifted their preferences from old crossbar technology to new SPC-technology. Simply expressed, SPC was cost-saving in both its use and its production, and also enhanced product quality and telephone service. Hence it was profitable for both producers and users, and almost every customer suddenly wanted SPC. This in turn speeded up the spread of SPC-technology among the remaining producers, also causing some new entries, e.g. by Telenokia in Finland. A similar "phased" reinforcement of buyer and seller diffusion happened a few years later in the transition from analogue to digital telephone switching.

FIGURE 2

Main Technological Substitutions in Telephone Switching



marks technological substitutions
marks a hierarchical classification of different systems

Preliminary

TABLE 1

Changes in the Telecom Industry During Different Technological Eras for Telephone Exchanges

Technological era	Beginning of era (decade)	Product examples	Expanding firms[1),2)]	Contracting stagnating firms[1)]	New entrants[2)]	Exitting firms[2)]
Manual system	1880s		LM Ericsson and others	?	Many	?
First automatic direct/indirect contol	1920s	"500-switch" (LM) Strowger (Siemens) Rotary (ITT) Panel-system (Bell)	Siemens ITT	LM	?	?
Crossbar technology	1940s	Crossbar (LM) Pentaconta (ITT)	LM ITT Siemens[3)] Northern (ATT)[4)]	?	Philips Japanese[5)] (Hitachi, NEC, Fujitsu)	0
SPC and digital signal processing	1970s	AXE (LM) Metaconta (ITT) System 12 (ITT) ESS-1 (Bell-ATT) System X (Plessey) DMS (Northern)	LM ITT (Metaconta) Northern (ATT)[4)] CIT- -Alcatel	ITT (System 12) Philips Plessey Siemens (?)	Northern[5)] Telenokia IBM-Rolm	ITT

Notes:
1) Rough estimates of changes in competitive position for major firms on important, competitive markets during the era. The list is incomplete. Mergers and acquisitions have occurred.
2) Only in some loose sense important firms. The list is incomplete.
3) Only major firm without crossbar.
4) Until recently a US monopoly prohibited to export.
5) New entrants on export markets.

6. Quantitative modelling

6.1 Notation and assumptions

For the sake of illustrating the main ideas, some simple quantitative modelling will be done next. The modelling is simple in the sense that only numbers of buyers and sellers are used as state variables for describing the market structure. We will first model the processes of entry of buyers and sellers into each new technology and then link these entry processes to exit processes. Then the interdependence between the arising buyer and seller diffusion processes will be modelled and finally technological development and substitution.

Consider first the two primary populations of economic agents on a market -buyers/users (B) and sellers/producers (S) of a product, say a camera. (We assume that the populations are disjoint and finite, possibly also time-independent.) This product is subjected to a stream of technological innovations over time, each innovation causing in each time period some buyers to switch over to using the new camera and some buyers to switch over to producing the new camera. If we assume that pure switching takes place, that is that the old is scrapped at the same time (you don't keep your old movie camera once you buy a video camera), we have at each time point four disjoint subpopulations: Users of the old product, users of the new product, producers of the old product and producers of the new product. Thus an innovation splits up the original two populations (B) and (S). In the case of two subsequent innovations we get six subpopulations etc.

Let us now use the following notation:

t	time variable, $t \geq 0$
t_i	time point for innovation no. i (a simple arrival stream of innovations is assumed); $i = 1, 2, ...$
$b_{ni}(t)$	cumulative number of buyers (firms) that have adopted the i:th innovation up til time t
$b_{ei}(t)$	cumulative number of buyers that have exitted the market for the i:th innovation as buyers up til time t
$s_{ni}(t)$	cumulative number of sellers (firms) that have taken up production of the i:th innovation
$s_{ei}(t)$	cumulative number of sellers that have terminated production of the i:th innovation, that is exitted the market as producers
$b_i(t)$	number of active buyers on the market for the i:th innovation
$s_i(t)$	number of active sellers on the market for the i:th innovation
$b(t)$	total number of actual and potential buyers at time t (b if time-indep.)
$s(t)$	total number of actual and potential sellers at time t (s if time-indep.)
$k_1, k_2, ..$	positive constants incorporating a.o. profitability expectations based on $\mathcal{E}_B$'s and $\mathcal{E}_S$'s
$T(t)$	vector of technological performance parameters realized as best practice at time t

Fluxional signs will be used for time derivatives, that is e.g. $\dot{s} = \frac{ds}{dt}$ Continous, differentiable variables are supposed to be adapted to the counting variables above.

We will also make a number of simplifications underlying the following presentation. First, the adoption and imitation decision processes are collapsed in such a way that each buyer and seller is either in or out the market for the new product (but still on the same basic market, as defined in more abstract terms). Thus each firm is in a binary state with respect to each market, as defined by each innovation. Re-entry is assumed not to occur.

Second, the variables $b_i(t)$ and $s_i(t)$ are chosen as descriptors of the state of the market for the i:th innovation. This is a crude state description of market structure but may be justified on the grounds that it is a reasonable first approximation. More importantly, if stability and equilibria are not attained in this simple state space, it will not be attained in a more refined (higher-dimensional) state space (superspace) either.

The following relations (balance equations) now hold:

$$\begin{cases} b_i(t) = b_{ni}(t) - b_{ei}(t), \quad i = 1, 2, \ldots & \text{(Eq. 1)} \\ s_i(t) = s_{ni}(t) - s_{ei}(t), \quad i = 1, 2, \ldots & \text{(Eq. 2)} \end{cases}$$

6.2 Entry processes

<u>Buyer side</u>

Traditional research on diffusion processes provides us with several models of $b_{ni}(t)$, e.g.:

$$\begin{cases} \dot{b}_{ni}(t) = k_1 \, (b - b_{ni}(t)) \, , \quad k_1 > 0, \; t \geq t_i \\ b_{ni}(0) = 0 \qquad\qquad t \leq t_i \end{cases} \qquad \text{(Eq. 3)}$$

(Linear diffusion model. Total market growth is proportional to the number of non-adopters)

or

$$\begin{cases} \dot{b}_{ni}(t) = k_2 \, (b - b_{ni}(t)) \;\; b_{ni}(t)/b, \quad k_2 > 0, \; t \geq t_i \\ b_{ni}(0) = 1 \qquad\qquad t \leq t_i \end{cases} \qquad \text{(Eq. 4)}$$

(Logistic diffusion model. Total market growth is proportional to the number of non-adopters, times the fraction of adopters).

Note that in these traditional models, technological diffusion among buyers is not explicitly dependent upon actions among sellers.

Seller side

Regarding diffusion on the seller side, there seems not to be much empirical research available (apart from research on typical process innovations). There is a great deal on innovation processes but not on imitation processes and the aggregate diffusion process that various economic agents' imitation processes give rise to. There are strong reasons to believe that seller diffusion in many cases differ from buyer-diffusion. The patent institute gives rise to a principal difference, for example. However, in the absence of empirical research we will simply assume that we can model seller diffusion in a similar way as buyer diffusion is modelled. In case an efficient patent protection gives a delay in the seller diffusion process we could use a time lag. Thus, in a case of simple logistic seller diffusion we have

$$\begin{cases} \dot{s}_{ni}(t - L_{pi}) = k_3 (s - s_{ni}(t - L_{pi}))\ s_{ni}(t - L_{pi}) / s & \text{for } t \geq L_{pi} + t_i \\ \text{and } s_{ni}(t) = 1 \ \text{ for } t_i \leq t \leq L_{pi} + t_i \,;\ s_{ni}(t) = 0 \text{ for } t < t_i & \end{cases}$$

where L_{pi} is the length of time the corresponding patent (if any) gives efficient protection of innovation no. i from imitation on the market.

In case the innovating firm sells patent licenses freely the L_{pi} could be dropped (or modified). In this case there is a buyer diffusion process for the license market.

Figure 1 over the diffusion of HFCS suggests that a simple model to fit to the data would be combinations of logistic buyer diffusion and linear seller diffusion. This model also gave the best least-square fit. These results suggest that there may be different diffusion mechanisms at work on the buyer and seller side respectively.

6.3 Exit processes

Regarding exit decisions at firm level (e.g. ITT in public switching or Amstar in HFCS-production) and exit processes on the market (e.g. how all traditional sugar producers in the US exitted HFCS-production), there seems to be almost no empirical research available yet for modelling purposes. Then we have to deal with special cases and assumptions to arrive at model specifications.

Buyer side

One possibility is to assume that

$$b_{ei}(t) = b_{n,\ i\ +\ 1}(t) \qquad \text{(Eq. 6)}$$

that is that the exit process is driven by the entry process in the next technology, that is a case of pure switching from the old to the new product, while no "technological leap-frogging" (that is to adopt innovation i + 1 without first adopting innovation i) is possible.

Seller side

Similarly, we could bluntly assume that the exit process on the seller side could be modelled likewise. However, as is well known, some manufacturers exit forever, as well as some new entrants are either entirely new firms or old firms outside the basic market, diversifying into it.

Also, a seller mostly has to offer products based on both old and new technologies, since there are usually buyers who have not yet switched to the new technology. For example, in public telephone switching the old crossbar technology will be offered for more than a decade ahead by some sellers, that is, they will produce both crossbar and SPC switches in parallel during perhaps 20-25 years. This could be modelled by introducing a time lag, L_{si}, which in fact partly depends on the pattern of buyer diffusion. Thus:

$$s_{ei}(t + L_{si}) = s_{n,\ i+1}(t) \qquad \text{(Eq. 7)}$$

6.4 Interdependence between buyer and seller diffusion

By viewing an innovation as giving rise to diffusion processes among both buyers and sellers, we are able to model that part of the interaction between buyers and sellers that results in interdependence between buyer diffusion and the seller diffusion. Several types of interdependencies are conceivable and could be introduced without explicit reference to pricing and profitability considerations. For example, by viewing the sets of buyers and sellers as two interacting sets of subpopulations, some analogies with studies of population dynamics in biology could be used. (Cf. predator-prey interaction leading to Lotka-Volterra type of equations.)

In order to illustrate below, we may simply assume a logistic buyer diffusion model and a linear seller diffusion model with linear interdependencies. Thus, we could assume that the entry rate at the buyer side is not only proportional to the number of non-adopters times the fraction of adopters but also to the number of sellers operating on the market and that the contributions are additive. Similar, the number of entering imitators is proportional to the number of potential imitators and on the number of potential buyers on the market.

6.5 Technological development and substitution

It is far from clear cut how to represent technological change in general. Let us describe the maximum level of realized technological performance in a certain field by a vector **T**(t) of technological performance parameters (e.g. the highest temperature for which superconductivity could be attained in reality at a certain time point or the number of elements per chip, chip size and line width in the semiconductor field). We then assume that the technology, as realized on the market, advances as the combined result of a revolutionary process and an evolutionary process. (Cf. Nelson and Winter 1982). The revolutionary process is represented by a stream of radical innovations occurring at time points t_i, producing large jumps in at least some component of **T**. The evolutionary process is represented by a continous upgrading of **T** between the time points t_i. The rate of change in the evolutionary process is further assumed to depend on the amount of learning that takes place among buyers and sellers. Sahal (1981) has demonstrated empirically how technological progress could be interpreted as the combined result of learning by producing (measured as cumulative output) and learning by using (measured as stock of products in use). Thus, it is reasonable as a first approximation to model as follows:

$$\dot{\mathbf{T}} = b_i(t) \cdot \mathbf{k}_5 + s_i(t) \cdot \mathbf{k}_6 \qquad \text{for } t_i \leq t < t_{i+1}$$

The coefficient vector $\mathbf{k}_5$ and $\mathbf{k}_6$ reflect the relative importance of learning by using and learning by producing. In some technologies the former is a dominant source of incremental technological advances (cf. von Hippel 1976), in some technologies learning by producing (learning by doing) is more important.

Note that modelled in this way technological evolution essentially is proportional to the integral of total sales over the product life cycle. The often observed S-shape of technological evolution then derives from the unimodality of the product life cycle curve.

6.6 Example of a full model

Thus, a full system of equations for innovation no. i (i=1,2,...) in the case of only one technological performance parameter and logistic buyer diffusion and linear seller diffusion with a linear coupling term looks like:

$$
B \begin{cases}
\dot{b}_{ni} = k_1(b - b_{ni}) \cdot b_{ni}/b + k_2 s_{ni} \;, \quad t \geq t_i,\ 0 \leq b_{ni} \leq b & \text{(Eq. 8)} \\
\begin{cases} b_{ni} = 1 & \text{for } t = t_i \\ b_{ni} = 0 & \text{for } 0 \leq t < t_i \end{cases} \\
\begin{cases} b_{ei} = b_{n,i+1} & \text{for } b_{n,\,i+1} < b_{ni}, \text{ otherwise} = b_{ni} \\ b_i = b_{ni} - b_{ei} & \text{for } s_i > 0, \text{ otherwise} = 0 \end{cases}
\end{cases}
$$

$$
S \begin{cases}
\dot{s}_{ni} = k_3(s - s_{ni}) + k_4(b - b_{ni}) \,, \quad t \geq t_i,\ 0 \leq s_{ni} \leq s & \text{(Eq. 9)} \\
\begin{cases} s_{ni} = 1 & \text{for } t = t_i \\ s_{ni} = 0 & \text{for } 0 \leq t < t_i \end{cases} \\
\begin{cases} s_{ei} = s_{n,\,i+1} & \text{for } s_{n,\,i+1} < s_{ni}, \text{ otherwise} = s_{ni} \\ s_i = s_{ni} - s_{ei} & \text{for } b_i > 0, \text{ otherwise} = 0 \end{cases}
\end{cases}
$$

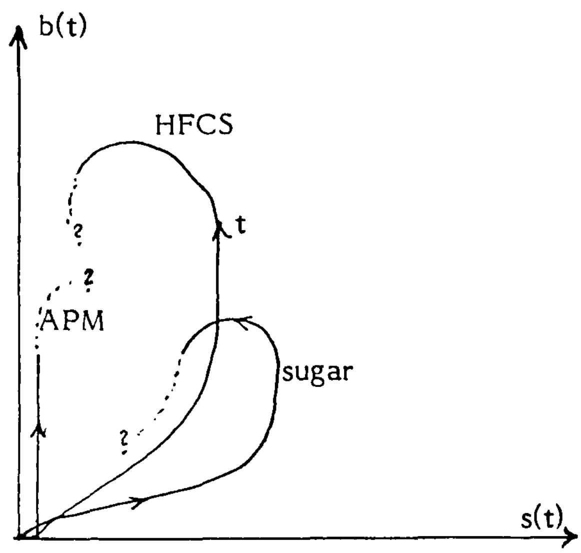
$$
T \begin{cases}
\dot{T} = k_5 b_i + k_6 s_i & \text{for } t_i \leq t < t_{i+1} \qquad \text{(Eq. 10)} \\
T(0) = 1 \ \text{(assumed w.l.o.g.)}
\end{cases}
$$

In case Eq. 8 is linear as well, and b and s are constant over time, the solution to the whole system consists of finite series of exponential functions in the interior of the solution region. Unfortunately, as soon as non-linearities are introduced, solutions are rapidly becoming difficult to find.

In principle the solutions for different i give a family of trajectories in the state space, describing in this simple framework the continous evolution of market structures driven by innovation processes. As new technologies arrive and entries into them drive exit processes (possibly lagged) from old technologies, the corresponding trajectories will even tually return to the origin. A dynamic (periodic) equilibrium could be conceived of but not a static one, unless technological developments stagnate. Figure 3 pictures this in principle in the sweetener case.

FIGURE 3

Principal Diffusion Patterns of Innovations in the Sweetener Market



6.7 An illustration by simulation

A number of simulations of the preceding model have been run in the absence of sufficient data and analytical tractability.[1)] Figures 4 and 5 present an illustrative simulation run.

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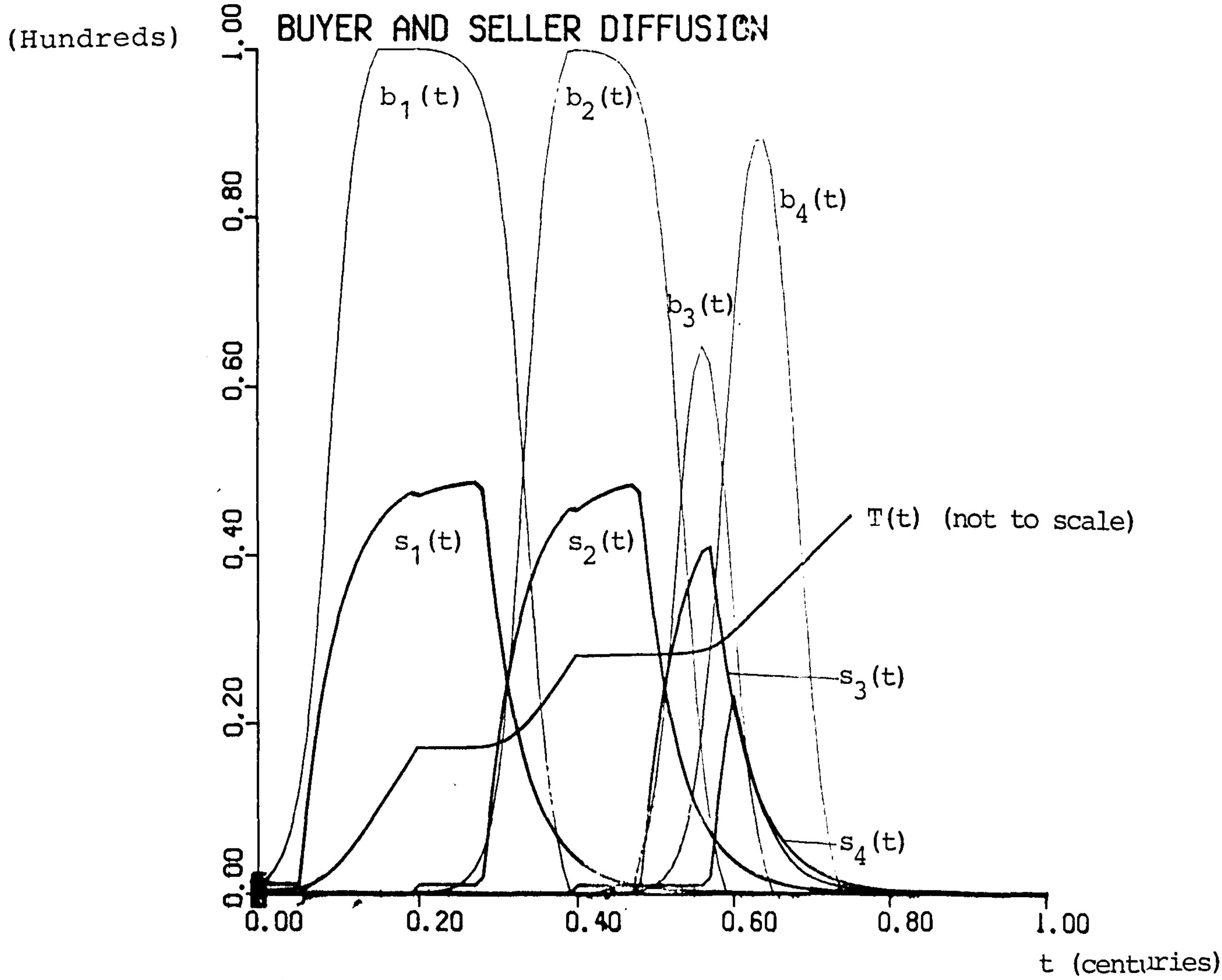
1) I am indebted to Mr. Tommy Forsberg who has run the simulations in ACSL (Advanced Continous Simulation Language).

FIGURE 4

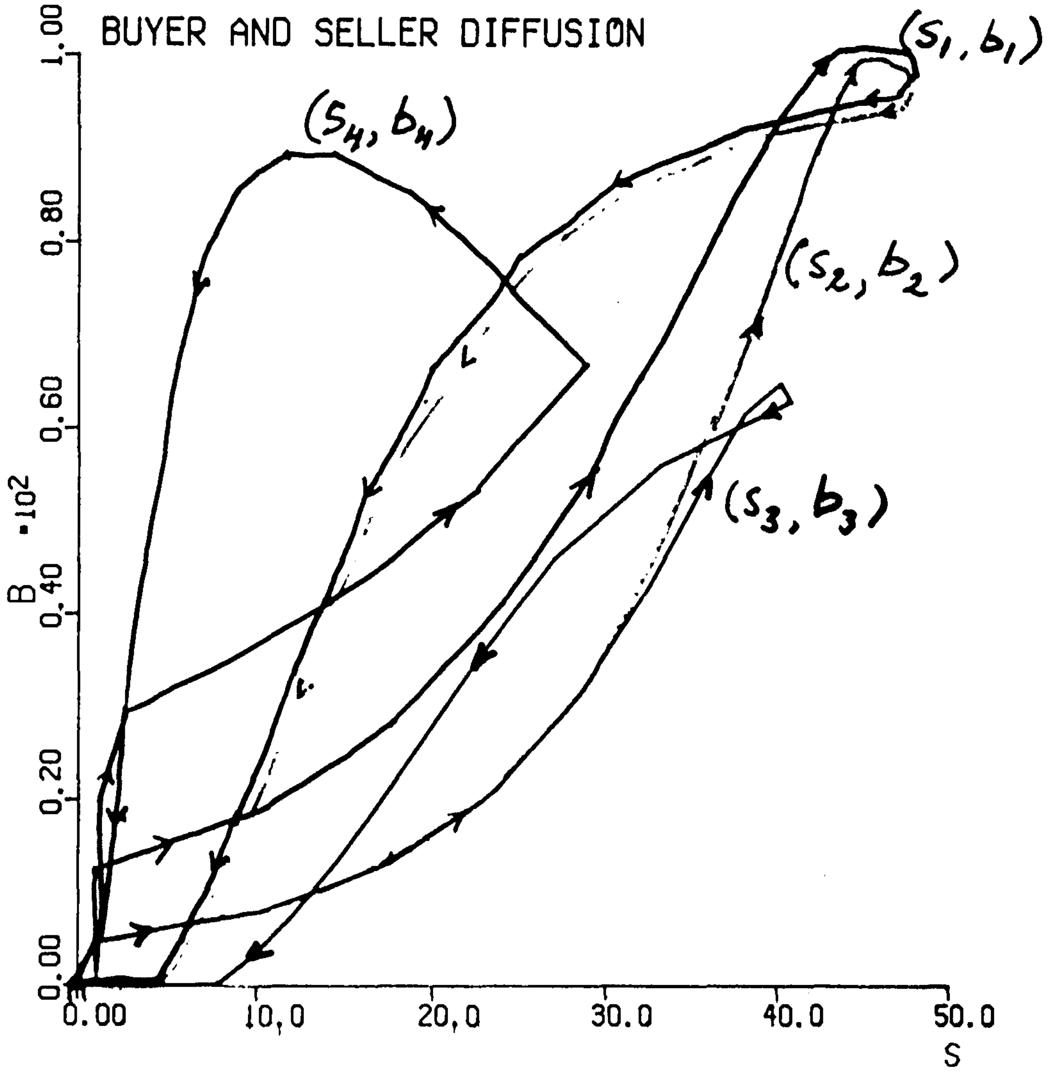
Illustrative Simulation Run of Four Innovations over Time



Parameter values: $b = 100$, $s = 50$, $k_1 = 0.5$, $k_2 = 0.05$, $k_3 = 0.2$, $k_4 = 0.005$,
$t_1 = 0$, $t_2 = 20$, $t_3 = 40$, $t_4 = 45$, $t_5 = 60$ (years)
$L_{p1} = 5$, $L_{p2} = 8$, $L_{p3} = 8$, $L_{p4} = 12$, $L_{p5} = 0$; $L_{bi} = 0$

FIGURE 5

Illustrative Simulation Run of Four Innovations with Time Parametrized



7. A concluding remark

Schumpeter's notion of "creative destruction" initially referred to the case when innovations were implemented by new firms. Thus, creative destruction applied at the same time to both the phenomena of product substitution and firm substitution by entry eventually forcing exit. History has plenty of examples of innovators making entry into an industry from the outside (e.g. electronic watches, calculators and pianos), as well as there are examples of firms within an industry exploiting a new innovation and eventually forcing some other firms to exit. (The notion of industry is, of course, not always clear.) However, product substitution does not necessarily imply firm substitution (and vice versa of course). Innovations may diffuse among both buyers and sellers without necessarily rearranging their competitive positions very much. The telecommunications industry, for example, has not had many innovation-based entries (on world markets) of new firms causing exits (yet) among existing firms in the industry.

What is conceivable is that companies cumulate a certain amount of managerial experience regarding technological substitutions and about how to react upon innovation diffusion. The more there is of this form of intergenerational managerial learning, the less technological substitution will cause industrial change in the form of firm substitution, everything else equal. There are some, perhaps small, signs that such learning gradually takes place. Companies today seem to be more alert in scanning new technologies and to be more aware of possibilities that innovations may occur outside their industry. For example, many companies today seem to be more eager to acquire technologies and innovative companies as a complement to their in-house R&D before these pose a competitive threat to them (see Granstrand 1982). This development seems partly to be in line with the thoughts of the old Schumpeter.

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