Industry Structure Dynamics and the Nature of Technology in the Hearing Instrument Industry

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Summary

The hearing instruments (hearing aids) industry is typically described as a technologically vigorous area. And yet, in the past 25 years, the structure of the hearing instrument industry has remained surprisingly stable. The article investigates the connection between industry structure and the nature of technology and applies the results on the industry. It is shown that market structure in both the industry and the supplying industries exerts strong influence on the nature of technological development, and that the technology in turn is to a large degree blocking changes in industry structure, especially entry and vertical integration.

JEL classifications: L11, L22, L63, O3

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1. Introduction[1]

It is a widespread opinion, ranging from recent business economists (D'Aveni, 1995) to more vintage economic studies (Gort, 1963; Caves & Porter, 1978) that industries with strong emphasis on R&D and technological development are more prone to be turbulent. And indeed, there are good reasons why new technology may facilitate entry and shifts in markets shares among incumbents.

If we expect technological development and turbulence to go hand in hand, the hearing instrument industry does not conform to this picture: Since the beginning of the 1970s - after the last major entry in the industry - not much has happened in the configuration of the industry. Basically the same companies participate, and the ranking order of companies has been more or less unchanged. At the same time, it certainly is an R&D intensive industry, with companies spending up to 12% of sales on R&D.[2] One reason for spending so much probably is the rich opportunities for technological development which has challenged the industry in the form of e.g. smaller and better integrated circuits for signal processing, smaller and better transducers and batteries, more powerful software plus an expanded fundamental understanding of sound and hearing.

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[1] This article draws heavily on Lee & Lotz (1998) which contains a more comprehensive description of the hearing instrument industry.

[2] 12% of net sales was what ReSound, according to its 10K filing, spent on R&D in 1996. Oticon spent 9% the same year. These two companies being among the most "aggressive" technologically, we suspect that 12% is a good estimate of the upper bound of R&D intensities in the industry, at least among the bigger companies. The lower limit is much harder to determine.

So the hearing industry stands out as an exception to some "normal" pattern. The purpose of this article therefore is, first, to comprehend the peculiarities in the hearing instrument industry leading to this outcome, and second, to expand our general understanding of the relationship between technological development and market structure evolution.

With our focus on stability, the study distinguishes itself from the majority of studies in this area, most of them examining situations of change. Our study is an investigation of an industry which is in a "mature" stage, trying to identify the factors accounting for stability.

Section 2 in this article discusses existing theories on this relationship. Section 3 is a description of the industry, and section 4 describes a particular innovation. In section 5 we reiterate the theoretical discussion, and in section 6 and 7 we analyze technology and economic organization, respectively, in the hearing instrument industry. Section 8 draws implications for the future development of the industry and for theory.

2. Technology and Turbulence

The relation between technology and market structure is being studied under many labels. A major part is carried out as entry-studies, such as studies that observe particular technological changes (innovations) and examine whether entrants or incumbents introduced the innovations.[3]

Another part is product life cycle studies that follow a particular industry over time, though often more interested in technology than in market structure. Our approach is explicitly focusing on the dynamics of the industry structure. This perspective is chosen because changes in the industry structure is at the same time the simplest and most comprehensive measure of the competitive situation. And the competitive consequences of technological development is our ultimate interest.

A measure of change in industry structure should encompass a number of elements: It should include entry and exit, and it should include a dynamic version of concentration measures, taking into consideration changes in market share positions among incumbents.[4] The

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[3] Henderson (1993) is not only an example of an innovative analysis that combines both economic and organizational perspectives on entry, but which also summarizes recent research in these areas.

[4] As Caves & Porter (1977) put it: "The theory of entry barriers has been limited unnecessarily by confining itself to the movement of firms form zero output to positive outputs. It becomes much richer - yet remains determinate - when set forth as a general theory of the mobility of firms among segments of an industry, thus encompassing exit and intergroup shifts as well as entry." (p. 241.) This perspective further lead Caves & Porter to define the concept of "strategic groups", that is, companies following similar strategies. Under the influence of Porter (1980), the companion term "mobility barriers" came to describe barriers to mobility *between* strategic groups. While mobility

concept of stability has been used at least since the 1960s (Gort, 1963), and it flip-side, turbulence, was introduced as the appropriate term by Beedsley & Hamilton (1984) to be applied, though, only to entries and exits in that study. Only in Acs & Audretsch (1990) expansion and contractions of incumbents was included under this label.

We combine two complementary research strands in this section: First we deal with the tradition for cross-sectional studies of stability. This tradition employs a well-developed concept for market structure stability, but as its purposes is a "screening" a wide range of potential factors influencing stability, its concept for technology is rather truncated, applying measures of R&D. Secondly we examine the research tradition which - typically on a case-by-case basis - has analyzed the effect of specific innovations on specific industries, but which has traditionally not been explicit about the market structure developments.

Cross-sectional studies

While the term "turbulence" is of recent date, the interest in the subject matter goes back more than 30 years. The stream of results is so "thin", however, that no strong, general results can be extracted. Comparing results from e.g. Gort (1963), Caves & Porter (1978), Acs & Audretsch (1990) and Davies & Geroski (1997) is difficult because of differences in populations studied (time and location) and because of differences in measures of turbulence as well as models and statistical techniques. Actually, none of the independent variables have the same sign of coefficient in all four studies.

Nonetheless, Davies & Geroski (1997) draw at least two interesting, though still preliminary, conclusions that are not totally at odds with the other studies: First, that "while concentration is typically fairly stable, this stability conceals considerable turbulence in market shares among leading firms" (p. 389), and second, that advertising, and (to a lesser degree) R&D and innovation plays a major role "in affecting both concentration levels and industry turbulence" (p. 389). That is, the more advertising and R&D, the more concentrated and at the same time more turbulent industries.

This result is partially at odds with Caves & Porter (1978). They found that high product R&D intensive industries are more turbulent than low product R&D intensive industries, while

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between strategic groups does contribute to overall industry turbulence, it remains only part of the concept of turbulence.

there are no differences in turbulence in low and high advertising intensive industries (p. 303).[5] Moreover, from their study it seems as if product R&D is creating more turbulence in highly concentrated industries than in fragmented industries. So while we may be skeptical about the role of advertising as a driving force in market share variation, the effect of product innovations seems to be corroborated in these statistical analyses.

Unfortunately, none of the studies were designed to identify the mechanisms through which advertising and R&D actually influence market structure change.[6] We therefore turn to a research tradition that is more explicit on this subject.

Product innovation as an engine of change in industry structure

Realizing that technology may influence structure differently in different industries, Caves & Porter (1978) tried to control for the the examined industries' stage in the product life cycle (Levitt, 1965; Abernathy & Utterback, 1978). The attempt did not yield any significant results, but it is a sign of the authors uncomfortableness with the variables normally employed in cross-sectional analysis. We need at more fine-grained set of variables in order to deal with technology as an economic phenomenon.

The question is *when* technological change - and especially product innovations - is destructive (in the Schumpeterian sense) and creates turbulence by allowing new companies into the industry, and perhaps even trigger a new product life cycle and coin a new industry? Or to use the expression from Abernathy & Clark (1985, p. 18): What can cause the "de-maturity" of an industry?

A starting point for this discussion is that if an innovation causes turbulence in an industry, and especially if it induces entry, it seems logical to infer that this particular innovation (or its imitation/adoption) poses non-trivial challenges to incumbents. On the other hand, if an innovation does not lead to entry and shift in market shares, the innovation probably has been easier to handle for incumbents. That amounts to saying that some innovations builds on the

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[5] It seems reasonable to expect R&D to be a more powerful disrupting force than advertising. With e.g. Sutton (1991, p. 314) it might be argued that the image of a company created by advertising may be carried over from one product generation to the next, providing the company with a competitive advantage largely independent of products. Changes in competitive positions based on changes in advertising therefore probably are relatively smooth. Contrary, a product innovation may immediately override the competitive position established on technology outdated by the new innovation.

[6] In particular, it is an interesting observation from the Davies & Geroski study that advertising and R&D at the same time prevents entry from newcomers *and* allow for turbulence among incumbents.

competencies that established firms must have already in order to be active in the industry, while other innovations require additional competencies and even may render incumbents' competencies obsolete. The "destructive" power of an innovation therefore depends on how "different" the competencies related to the new technology is from the competencies of the old technology.[7]

In a number of papers, Tushman and Anderson[8] have pursued this idea by proposing the dichotomy of competence-enhancing and competence-destroying technological discontinuities (read, innovations). Only if innovations tend to destroy existing competencies in the industry, are we to expect entering firms to be able to out-compete incumbents. Although it is conceptually obvious that what ultimately determines a company's chances of survival is its competencies (in this relation, competencies to create, imitate or adopt innovations), it is also clear that the *empirical identification* of such competencies is not an easy task. Technology is a truly multifaceted entity, and company competencies are probably even more so. Also, competencies are "relative" to the competitive environment, so what in one situation is a unique competence may in another situation have no value at all. To approach the question of the degree of difference between sets of competence profiles directly, without a well-defined categorization or typology of competencies, therefore seems difficult and subject to great subjectivity. Even if a one-by-one assessment of each innovation turns out to split a sample of innovations in two relatively distinct types (as it apparently does in the samples of Tushman & Anderson), such a method is very difficult to replicate by other researchers on other samples (or even the same).

A related research strategy attacks the question from the technical side, trying to identify features of an innovation that may cause disturbance. This is in line with a long-standing tradition which has come up with such dichotomies as "radical" versus "incremental" innovations. Recently, Henderson & Clark (1990) has added a new dimensions to this tradition by distinguishing between two types of potentially disruptive innovations: Radical innovations and architectural innovations. While these authors define a radical innovation as one which

[7] Note that what matters is the "degree of difference" in competence profiles required for innovation/imitation of a new technology. The "height" of innovation, that is, the degree of improvement in performance of the new technology over the old, should not directly influence an innovation's effect on turbulence, because even very dramatic improvements in performance are easily imitated if rivals have the relevant competence profile. However, even quick imitation is never instantaneous, and first-movers may enjoy other advantages such a creating brand loyalty or setting standards. Therefore, it should be expected that while the degree of "difference" in competencies required for its imitation/adoption is the major determinant of an innovation's disruptive effect, the height of the innovation will amplify this impact.

[8] See e.g. Tushman & Anderson (1986) and Anderson & Tushman (1990).

changes both the "core concepts" (e.g. components or basic technologies) and the linkages between these concepts (that is, the architecture of the product), the architectural innovation "only" changes the linkages between core concepts, "recycling" the elements. (These two types of innovations are compared to two other types, modular innovations and incremental innovations, which are not expected to have disruptive effects.)

Henderson & Clark (ibid.) argue that both radical and architectural innovations often create difficulties for established firms and that they may even redefine the industry, but somewhat contrary to expectations, they also argue that architectural innovations are potentially more disruptive than radical innovations. While a radical innovation "creates unmistakable challenges" (ibid., p. 13) and therefore calls for immediate action, architectural innovations are more subtle in the sense that "(m)uch of what the firm knows is useful and needs to be applied in the new product, but some of what it knows is not only not useful but may actually handicap the firm" (ibid., p. 13). This may be a confusing situation and even if the problem is correctly comprehended it may be difficult to handle, as major parts of the company's competencies and organization may be structured around a specific architecture of the product. The company needs to re-build its architectural knowledge, that is, the knowledge that allows the company to understand and improve the linkages between the elements of a product. But "(b)ecause (established firms') architectural knowledge is embedded in channels, filters, and strategies, the discovery process and the process of creating new information (and rooting out the old) usually takes time" (ibid., p. 18). So while the competencies for improving core elements of a product may be readily identified (and if not easily then often at least possibly replaced), then the competencies needed for architectural innovation are both more difficult to identify and to replace.

Whether Henderson & Clark are right in conjecturing that architectural innovations are more disruptive than radical innovations should be left for an empirical test (if testable at all, see our case in section 4), but the idea that the changes in architecture (or basic design) may create more turbulence among competitors than changes in the elements of the product is one step towards an understanding of the influence of technology on industry structure. And it corresponds well with the idea of a dominant design whose emergence often seems to lead to considerable exits from an industry.

Summing up upon the two approaches, Anderson & Tushman focus on the competencies needed for a specific innovation, that is, characteristics *not* of the innovation directly, but of some requirements to produce it. Henderson & Clark attempt to identify features of the *innovation* that may cause changes in industry structure. The two approaches clearly are not mutually exclusive: The Henderson & Clark acknowledges that in the end it is the endowment of competencies that determines a company's commercial success, but instead of attempting a direct identification of the relevant competencies, Henderson & Clark claim that some technological changes are of a kind that inevitably must challenges incumbents as much (or even more) as they challenge entrants. While such an approach clearly is a roundabout "detour" compared to the approach of Tushman & Anderson (and possibly only a first step towards a full understanding of the relationship between technology and industry structure), it does make sense if we have better chances of analyzing technologies than competencies. That is the case, in our opinion, not the least because researchers seldom have access to internal studies of all (or most) companies in an industry.

In a study of the impact of technological change on industry structure, the advantage of the Henderson & Clark approach is that a researcher can observe technology only in order to operationalize the explanatory variable, while in the Tushman & Anderson approach the study must deal directly with (and indeed somehow measure) competencies in incumbent firms and in entrants for old and new technology, respectively. One disadvantage of the Henderson & Clark approach is that it reduces explanations to only one dimension of technological change (architectural or not), and even this measure is not easily applied to empirical research. We will illustrate this problem in section 4, arguing that Henderson & Clark cannot escape the question of competencies. First, however, section 3 will present the hearing instrument industry.

3. The Hearing Instrument Industry: Structure and History[9]

The hearing instrument industry as we term it today has existed for about 100 years. The industry is concerned with alleviating hearing impairment (specifically, so-called sensorineural hearing impairment) with external hearing instruments. Defined this way, the boundary of the

[9] More information on the data sources may be found in Lee & Lotz (1998).

industry is relatively clear-cut. It does, for example, not include implants[10] or other medical/surgical solutions to hearing problems.

The hearing instrument industry is not a large industry. Total revenues was in 1994 app. $1 billion (wholesale prices) on a worldwide basis, and the number of instruments produced is some 5 million a year (Frost & Sullivan, 1994). Growth is moderate and relatively steady. The US market is the largest single market, accounting for almost 40 pct. of the total world market revenues.

Present industry structure

The structure of the industry seem to be relatively fragmented. No one company dominates the world industry, and worldwide almost 200 companies claim to produce hearing instruments. However, many of these companies are small, locally oriented and technologically unsophisticated.

Table 1 provides a list of all companies having launched "programmable hearing instruments" at the US market. Programmable hearing instruments were, until recently, the most advanced instruments in terms of signal processing. This is not necessarily a list of the world's largest companies, but the companies on the list have all shown a certain technological commitment to the industry. For the non-American companies appearance on the list also is a sign of international orientation. There are 20 companies on the list, six of which, however, are subsidiaries of other hearing instrument companies. On this basis it seems fair to say that a roster of about 15 companies (with subsidiaries) would be sufficient to cover all important players in the industry.

[10] Cochlear implants are not substitutes for hearing instruments.

Table 1

Hearing instrument companies with programmable instruments, 1997				
Founding year	**Start of hearing instr. production**	**Company name**	**Headquarter**	**Ownership**
1979	1979	Argosy	MN, USA	Private
1994	1989	Audio 'D'	PA, USA	Private
1940	1940	Beltone	IL, USA	Private
1925/1936	1947/1936	Bernafon-Maico	Switzerland / MN, USA	Oticon (1996)
1948	1948	Dahlberg (Miracle Ear)	MN, USA	Conglomerate
1943	1943	GN Danavox	Denmark	Conglomerate
1976	1979	Hearing Services Internat.	MN, USA	Argosy (1988)
1986	1986	Micro-Tech	MN, USA	Private
1981	1981	Omni Hearing Systems	TX, USA	Starkey (1988)
1904	1946	Oticon	Denmark	Public
1891	1948	Philips Hearing Instrum.	The Netherlands	Conglomerate
1947	1947	Phonak	Switzerland	Public
1954	1954	Qualitone	MN, USA	Starkey (1996)
1984	1984	ReSound	CA, USA	Public
1956	1956	Rexton	Germany	Siemens (1986)
1847	1910	Siemens Hearing Instrum.	Germany	Conglomerate
1996	1990	Sonar (3M)	MN, USA	ReSound (1996)
1963	1971	Starkey	MN, USA	Private
1964	1964	Unitron	Canada	Private
1956	1956	Widex	Denmark	Private

Notes: In cases when founding year is after start of hearing instrument production, the present company is continuing activities from other companies.
The years in parenthesis under ownership are the years of take-over.
The years for Bernafon-Maico represent Bernafon and Maico respectively, since both companies were active hearing instrument manufacturers before they were merged in 1986.
Sources: The list of companies appeared in Hearing Journal, May 1997.
Information about years is from Skafte (1996), Hearing Journal, Nov. 1997, company web sites or direct inquires.
Information about headquarters is from Hearing Journal, Dec. 1997.
Information about ownership is from Hearing Journal, Nov. 1997, web-sites or direct inquires.

It appears that the companies are concentrated in relatively few geographical areas: In North America, Minnesota (Minneapolis), and in Europe, Denmark hosts a disproportionate number of companies. No Japanese companies appear on the list. Only one Japanese company, RION, seems to operate internationally.

Looking at overall *market shares,* Siemens was in 1996 the largest company, followed by Starkey and Oticon,[11] all of them with market shares roughly between 15% and 20%, according to industry participants.[12] Probably 80% of the market is covered by the 9-10 largest companies.

There are two main types of hearing instruments in terms of design: 1) Behind-the-ear (BTE) instruments, which have a case behind the ear connected via a small plastic tube to an ear piece, and 2) instruments with all parts in one case placed *in* the ear. The latter type may be subdivided in a) the traditional in-the-ear (ITE) instruments with the case fitted into the outer ear, and b) in-the-canal (ITC) instruments and c) completely-in-the-canal (CIC) instruments which are very small and almost invisible since they are placed deeper in the ear canal. Overall, BTE is the most popular type of instrument, covering app. 55 pct. of the world market, but its share is slowly decreasing. In the US, ITE instruments have long been the most frequently dispensed instrument, now rapidly being substituted by ITC/CIC instruments (Frost & Sullivan, 1994).

A breakdown of the world market into three product types (see table 2) reveals a structure with a clear leader in each segment, especially in the ITE and ITC products. (These latter product-markets are dominated by North American companies, probably because of the preference for that type of products in that geographical area.)

The structure of each of the three product segments is roughly the same: A leader accounting for 24-31 pct. of the market followed by a handful of important players with 6-15 pct. market share. The degree of concentration varies, however, slightly. The "old" product (BTE) has a less concentrated structure (a Hirschman-Herfindahl index, HHI, of app. 1000), while the "newer" ITE (with a HHI of app. 1400) and especially the "newest" ITC product (HHI of app. 1600) are slightly more concentrated.

A closer look at the seemingly fragmented structure in the hearing instrument industry therefore reveals a concentration that qualifies the industry as an genuine oligopoly with three leading companies.

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[11] The market share of Oticon has increased considerably since 1993 (table 2), due mainly to the acquisition of Ascom Audiosys (Bernafon) (see below).

[12] In 1997 Starkey Laboratories had annual sales of $300 million and 2,350 employees (Ward's Business Directory 1998), while Oticon (the group) in 1996 had a net turnover of app. $165 million and employed some 1,700 persons (company web site). Figures on Siemens' hearing instrument activities are not available due to the group structure.

Table 2

Hearing instruments World market shares (revenues) in three product areas (percentages), 1993			
	Behind-the-ear	In-the-ear	In-the-canal
Siemens	24	14	12
Oticon	10	<5	<5
Danavox	9	<5	<5
Philips	7	<5	<5
Phonak	7	<5	<5
Widex	6	<5	<5
Starkey	<5	29	31
Miracle Ear (Dahlberg)	<5	14	15
Beltone	<5	10	12
Argosy	<5	8	8
Note: *<5* means a market share of less than 5 pct. in that product area. Source: Frost & Sullivan (1994)			

Industry history

In 1953 the transistor (invented in 1949) made it into hearing instruments, allowing new and smaller designs, not only because of the transistors themselves but also because of lower power demands and therefore smaller batteries (Bergenstoff, 1993; Hearing Journal, Nov. 1997). Many different designs competed, and only late in the 1960s the eventual winning design, the BTE instrument, gained more than a 50% market share in the US. The companies engaged in this turbulent battle were on the one hand the old, "pre-transistor" companies, and on the other hand the range of new, truly "electronic" companies, established in the 1950s. Few new companies entered in the 1960s, perhaps due to the slow growth in sales.[13]

Barely established as an industry standard, the BTE instrument was challenged by the ITE instrument. Actually, as early as in the mid 1950's both Danavox and Miracle Ear had presented hearing instruments which had all parts in one shell in the ear. In 1968, this type of products had captured only 9% of the US market, increasing however to 31% in 1977. (Hearing Journal, Nov. 1997). In 1983 ITE instruments had captured more than 50% of the US market

[13] In the mid 1950 US-sales increased rapidly, but during the decade from 1958 to 1967, unit sales increased only 25% to about 400,000 (Hearing Journal, Nov. 1997). From 1967 sales increased until 1972, only to fall back to the 1967-level in 1977 (due to a Federal Trade Commission intervention). From then on, however, sales increased rapidly.

(Cranmer, 1985), and from that time ITE (with its sub-types of ITC and CIC) has dominated the American market. Today, only 16% of the instruments sold in the US are BTE.[14]

The development of ITE instruments was spurred by the miniaturization of components (e.g. batteries and microphones) and the development of integrated circuits. With these advances, it technologically seemed to be a bigger problem to make high quality, reliable ITE instruments than to make them small (Oticon web site on the hearing aid history). The major problem for the penetration of ITE instruments was therefore not technological, but logistic: While BTE instruments are standard products, ITE instruments are custom-made since the whole ITE instrument must fit the ear perfectly (Bergenstoff, 1993). It was the American company Starkey that first solved that problem, entering the industry from the distribution-side: The company was founded in 1961 as a dispenser, expanded with a molding laboratory in 1968, and introduced ITE instruments in 1971. (Section 4 is devoted to the ITE innovation.) Although Starkey earned a clear first-mover advantage, other companies followed, and by the mid 1970's ITE instruments were well established products, at least for the US companies.

From this time on, we thus have the two main hearing instrument designs.[15] The industry had found its "shapes", its "dominant designs", thereby moving from "adolescence" to "maturity". Of course technological development did not come to a halt with that, but most uncertainty about the overall design of a hearing instrument was eliminated.[16] We therefore divide the newer industry history in two distinct periods: One ranging from the introduction of transistors in 1953 to the establishment of the dominant design in the mid-1970's, and one covering the following two decades. In section 4 we return to the ITE innovation, but for the remaining part of this report, our focus will be on the latter period in an attempt to understand the stability of the industry in this period.

Beyond the pure technology, however, there is another reason for choosing the mid-1970's as a turning point: In the first period, US distribution started with dealers marketing normally only products from a single manufacturer. For example, Beltone, established in 1940, set up a national network of dispensers exclusively dealing with Beltone instruments already in 1941(Hearing Journal, Nov. 1997). During the 1950's and 1960's this system was gradually

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[14] BTE is still the preferred type in the rest of the world.

[15] To some degree they are substitutes, but the also have different applications: The BTE's are especially good for children and for persons with severe hearing losses.

[16] Other types of uncertainty persists, though. See section 5.

abandoned and by the mid-1970's it only included a minority of distributors. The single-line marketers were substituted by more independent multi-line dispensers, carrying instruments from several manufacturers. One major reason for this change was the emergence of the "clinical referral system". Under this system, a medically trained "audiologist" examines the patient and prescribes a specific brand and model of instrument, which is then provided by a dealer (Skafte, 1996). To be able to benefit from this system, dealers had to carry many different models. Also pushing this development was that the Federal Trade Commission - for antitrust reasons - intervened and required one manufacturer to stop requiring distributors to sell only that manufacturer's products in 1953 (Skafte, 1996).

But if dealers changed by expanding from a single to multiple brands, some referring audiologists felt unhappy about their status, too: They felt that they should not only choose the hearing instrument for the end-user but also provide it. This was, however, considered "unethical" by many, especially the association of audiologist. Nonetheless, some audiologists started dispensing instruments around 1970, and in 1978 it was legally enforced that audiologists could also sell hearing instruments (Hearing Journal, Nov. 1997).

While still considered two different types of dispensers, the former franchising single-line dealers and the dispensing audiologists both converged towards the now well-known American hearing instrument dispenser. Not only legally independent from manufacturers, dispensers also became more and more competent in choosing which instruments to fit a particular patient: The 1950's and the 1960's saw the growth of numerous "hearing health care clinics" throughout the world. As a result of their research hearing instruments were improved (Bergenstoff, 1993). But also the general knowledge about hearing was enhanced, and many new measuring instruments were developed. Equipped with more knowledge and with new measuring instruments, the dispensers came out of the first period as a truly independent and indispensable part of the American hearing health industry.

Industry structure development

As shown in table 1, all existing European companies and many of the American companies have been active since the 1950s. The 1960s was a particularly quiet decade in terms of *entry*, and except for the important entry of Starkey, only in the late 1970s we saw some entry activity again, maybe spurred by the growth in US sales from 1977. The 1980s witnessed a handful of entries, typically based on some proprietary technology. These companies have yet to prove that they will be long-term survivors.[17] Overall, entry has indeed been limited.

Also, there has been relatively little *merger and acquisition activity* within the industry. Starkey did buy a couple of small companies in the 1980s, and in 1993 Dahlberg was acquired by Bausch & Lomb (US), which, however, had only minor activities in hearing instruments. More important in terms of industry structure was the 1995 Oticon acquisition of the Swiss company Ascom Audiosys (Bernafon-Maico), since its size was about a third of Oticon (after Ascom's acquisition of Bosch's (G) activities in hearing instruments). Also ReSound has been active: It acquired Viennatone (AUT), and in 1996 it bought 3M Hearing Health (renamed SONAR) whose patents were an important asset.

Data on long-term *market shares* would be the "correct" measure of structural development, but unfortunately is not available. There is, however, strong indications of stability: Over the past two decades, it has been the industry's opinion that Siemens, Starkey and Oticon have been the leading companies worldwide. Furthermore, over the past three decades the three Danish companies (Oticon, Danavox, and Widex) together have been said to cover one quarter of world demand.[18] These two statements are confirmed by the different (and incommensurable) figures on market shares that we have had access to (non reported). But again, accurate long-term data on shares are not available.

The overall trend in hearing instrument industry structure since the mid-1970s, therefore, is one of stability, when assessed by measures as entry and exit, mergers and acquisitions, and market shares.

4. The Transition to the Mature Stage: A Case of an Architectural Innovation

Starkey's entry into the industry coincided with the introduction of an important innovation, the in-the-ear (ITE) instrument, which - as we have described - turned out to become a dominant design alongside with the BTE instrument. The innovation was made possible by the ever decreasing size of components. Technically, an ITE instrument is little more that standard components packaged in another type of case. Already in the 1950s many companies developed

[17] While having achieved market share, the most successful of these companies, ReSound (founded in 1984) still has not been operating in black.
[18] That was probably slightly overestimated in the 1980s, when they struggled to adjust to the customized ITE production.

ITE instruments, but they never succeeded in the marketplace. So Starkey was not the first company to produce an ITE instrument, but Starkey as a small, up-coming company entering the field did succeed.

It took only a couple of years before competitors were able to produce similar products, if they did not carry ITE products already. But still only Starkey succeeded in commercializing ITE instruments. If the basic lay-out of an ITE instrument did not diverge much from a BTE instrument, *organizationally* it required a shift from to-the-shelf production to customized production, since every ITE case has to be moulded to the individual customer, and components have to be arranged in order to fit the specific case. Starkey, new as manufacturer but well established already as dispenser of hearing instruments, was able to set up an organization that could handle this problem. That turned out to be more difficult for the existing companies. They had little technical problems in developing another ITE instrument, but many problems in changing their internal organization. So while this innovation was only modestly new in technical terms, it required an all new logistics system which was not "compatible" with incumbents' logistics systems.

Here we probably have a pretty clean example of an innovation that was not at all "radical" in technical terms. It did not challenge the use of existing "core concepts", and neither did it challenge the fundamental linkages between these components (although it turned out that "feed-back" problems increased with the shorter distance between microphone and speaker in an ITE instrument). The challenge was a truly organizational question: How to set up a logistic system that could efficiently handle customized production? With most technological competencies acquired in the production of BTE instruments still highly relevant, it may have seemed to be a "piece-of-cake" for the incumbents to cope with the challenge from Starkey initially. But as Henderson & Clark suggest, the fact that most of the more visible competencies are still relevant may actually distract attention from the fact that an underlying condition for competition has changed, leading incumbents to downplay the importance of the innovation, and thereby allowing the innovator considerable lead-time.

So the ITE instrument was a seemingly innocent innovation that - because it could only be commercialized within an entirely different logistical set-up - turned out to allow new entry anyway. The Henderson & Clark approach seems to have explained the situation. The only problem is that we have no guidelines for the *ex ante* identification of the architectural aspects of an innovation. We would not pretend, at least, that we *ex ante* would have been able to point out the disruptive potential of the ITE innovation by classifying it as an architectural innovation. This is a strong reminder for research in this area, because it highlights the elusive character of our conceptualization of technology: Even a reasonably carefully defined concept as "architectural innovation" is hard to operationalize. This problem virtually prevents rigorous testing of the Henderson & Clark hypothesis, and leaves this field of research without much predictive power.

While the focus on the conspicuous events of change therefore has not produced any breakthroughs in our conceptualization of technology, we might find it productive to examine the flip-side of change, i.e. stability, and try to combine lessons from this area with the lessons from the studies of change. The remainder of this paper therefore deals with a period in the hearing instrument industry that is particularly quiet in terms of market turbulence.

5. Problems with Exiting Models, and an Alternative

Based on our theoretical discussion in section 2 and the ITE case in section 4, it is our contention that it probably is a futile effort to try to classify innovations according to such simple features as whether they are competence destroying or not, or whether they *per se* are radical or architectural or in other ways possess "destructive" power. In essence, the problem is the whatever we define as architectural or radical, ultimately is relative to some existing technology, and, even worse, the competencies required to produce/imitate/adopt a new technology must be compared to existing technologies.

Both technology and competencies are simply too multidimensional and dynamic to be forced into such rudimentary categories as suggested by Henderson & Clark and Tushman & Anderson. Classification of historical data will therefore almost inevitably be more or less tautological: Since the different types of innovations/competencies cannot be precisely defined in general, the specifics of the particular industry and its technology will have to be included in the definitions, hence allowing for self-fulfilling prophecies, and - by the way - hindering cross-sectional comparison.

And even if we - against all odds - succeeded in predicting which kinds of innovations actually have disruptive effects, starting the analysis with the classification of innovations in a sense amounts to closing one's eyes for the really interesting subject: Where do these innovations come from? Are there types of technologies and economic organization that facilitates the production of disruptive innovations more than others? The kind of analysis that looks at the effects of different kinds of innovations on market structure (e.g. whether the disruptive innovations are more frequently introduced by entrants or incumbents) still take innovations as "manna from heaven", only that manna now comes in two different shapes. And the research tradition that has looked upon the effects of markets structure (firm size and concentration) on innovative activity remains inconclusive (Henderson, 1993; Cohen 1995).

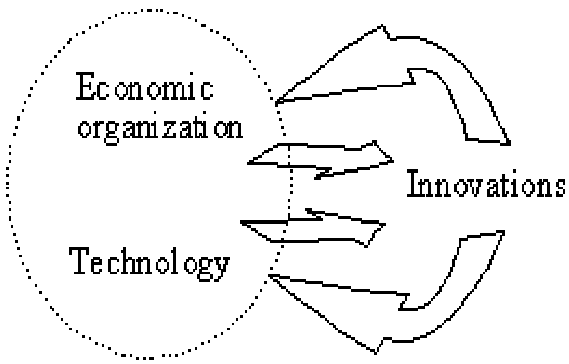

Figure 1

All in all, from a cognitive (science development) point of view, the situation in definitely unsatisfactory (see also Rosenbloom & Christensen, 1994). Figure 1 may help understand the degree of our ignorance. Technological development and industry changes obviously are not independent, they co-evolve in some complicated way. Illustrating this relationship, figure 1 features innovations as the "vehicle of change", since innovations both changes the competitive positions of rivals in the industry and adds to the pool of technology. In the figure, the term "economic organization" is taken to embrace the state of the industry structure as well as the structure of adjacent industries (most notable suppliers and customers).[19] Innovations are depicted as a product of the current state of economic organization and technology. Technological and structural change is an iterative process where a certain state of economic organization and technology produces innovations that affects the state of the world than in turn produces new innovation and so forth.

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[19] Michael Porter's (1980) Five Forces framework captures well our intentions with the concept of economics organization.

As suggested above, our knowledge about the upper two relations is scattered: We know very little about how economic organization influences the innovative activity, and we have no good concepts to apply in the study of the effect of innovations on economic organization.

The figure conveys a rather complex view of the world, much more comprehensive than the partial analyses of e.g. the effect of radical innovations on entry. And yet it pretends only to explain parts of the changes in economic organization (and technology). In the real world, many other factors influences these variables. This representation of the world , however, urges us to focus our attention on the co-evolution of economic organization and technology over time. Instead of calling attention to the characteristics of discrete innovations, it emphasizes the more general nature of technology of an industry and the development over many "cycles". It naturally leads to a search for regularities in the patterns of technological development and for similarities across innovations.

And certainly, we would argue that the traditional, partial research strategy focusing on only one out of many interfaces actually is a major reason behind of the lack of research results in the field of technological change. Admittedly, it is easier to test relationships between one dependent and a limited number of independent variables, but if these variables are themselves part of a much larger system with many other interactions, it make little sense to try to control for some or them; such relationships must be spurious.

On the other hand, we are not well equipped to handle such complex relationships. We need some "constants" in order to deal with complexity. If, however, complexity is reduced, such as in the case where the economic organization is left unchanged over a long period, we might have a chance of including the whole picture in our analysis. In stable industries events are repeated relatively frequently, and it therefore makes sense to look for factors that consistently constrain the degrees of freedom in innovative activities and limit the effects of technological innovations on competition.

Despite he problems, here actually are attempts at such comprehensive analysis: The product life cycle as formulated by Abernathy and Utterback (1978) may be taken as a specific version of the perspective in figure 1. With no intention of applying the grand idea of a sequence of stages, together constituting a product life cycle, our analysis of the hearing instrument limits itself to a period in this industry's life that - with reference to other versions of the product life cycle model - may be termed "maturity". So instead of explaining change and discontinuities, which is the inherent purpose of the major part of innovation studies, our interest is in explaining stability. As we have described in section 3, the hearing instrument industry from the beginning of the 1970s to the end of the 1990s seem to be a good case of stability.

Faithful to figure 1, we shall divide the analysis in two, starting with the state of technology in the industry, and then turning to its economic organization.

6. The Nature of Hearing Instrument Technology

Hearing instruments, no matter size or type of signal processing, are made up of roughly the same elements: A microphone, an amplifier, and a receiver (loudspeaker) is the technical core, powered by a battery. Adjustments may be made by switches and trimmers (small plastic items) or, in the so-called programmables, by a programmed chip. The digital instruments have digital amplifiers plus additionally an A/D and a D/A converter to change the analog sound received to digital signals processed in the amplifier and back to analog sound to be send to the ear.

Even though a hearing aid therefore, *superficially*, is a standard electronic device with well-known components and should be able to benefit from the now "generic" technologies of electronics, the improvement of hearing instruments has not been a trivial process. It turns out that it has in fact *not* been possible simply to transfer technologies from other electronics fields. No other field has had so tough *limits on space*, so many development problems are unique to the hearing instrument industry.

Obviously, the space limits influence the choice of power source. Only very few electronic components are designed for 1.4 voltage. Currently that has required the development of not only specialty circuitry capable of running on low voltage, but also the necessary development tools (e.g. mathematical simulations).[20] Besides the electronics, the small size also posed mechanical and acoustical problems. Most notable is the (still partly unsolved) problem of feedback from the receiver to the microphone.[21] As we will discuss below, the severe space limits have decisive consequences for the nature of technological development because of strong interdependencies among components.

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[20] This is the main reason why we only now witness the introduction of digital sound processing in hearing instruments, a technology that has been available in standard Hi-Fi equipment for decades.

[21] Conversation with Torben Poulsen, Department of Acoustic Technology, Technical University of Denmark, November 1997.

Development objectives

Beyond the pure technological problems, hearing instrument development is hampered by the uncertainty in development objectives[22] stemming from the fundamental problem that hearing is a complicated physiological phenomenon, which is not thoroughly understood.

One of the reasons for the problems of understanding hearing is that - in contrast to glasses, which can fully compensate for a reduced ability to see - hearing instruments send amplified sound into a *genuinely defect* organ. Eyes may be defect also, but usually the lenses are just not "focused". A hearing instrument cannot repair a hearing impairment, but can to some extent alleviate dysfunctional hearing. However, the auditory system which a hearing instrument is targeted at is still not fully understood, and it requires a multiplicity of disciplines (e.g. physics, anatomy, psychology, chemistry, neurology) to advance knowledge in this field. This implies that in order to understand and alleviate hearing impairment, a number of professions need to become involved.

A first consequence of the lack of understanding is that it is still not clear which technical solution is actually best for the users. The situation in hearing instrument technology is one of relatively rich technological opportunities, but only vaguely identified development targets.[23] The basic understanding of hearing does not point at any clear ways of how to substantially improve the performance of a hearing instrument.

Since we still do not know all about what hearing is and therefore not all about what the different kinds of hearing losses are, the industry is left searching for the optimal hearing instrument. Much development in hearing instrument is therefore a trial-and-error process, since no formal model can prescribe the optimal construction of a hearing instrument.[24] Not only is trial-and-error important for finding the best technical solution to a given development task, but trial-and-error is necessary also to find out which development tasks to strive for, that is, which

[22] We are here dealing with the difference between "functional" uncertainty and "technical" uncertainty in development processes (see Freeman, 1982; Lotz, 1991). While technical uncertainty relates to problems of reaching a well specified technical objective, functional uncertainty refers to the problems of choosing the optimal technical specification, that is, the best design of the product.
[23] Conversation with Torben Poulsen, Department of Acoustic Technology, Technical University of Denmark, November 1997.
[24] Rosenberg (1982) describes the development of aircrafts, which took place also without a formal model of the performance of airplanes. Instead, according to Rosenberg, the development process relied on learning-by-using (trial-and-error processes being inappropriate for airplanes!).

type of instrument (features, size etc.) actually meets the users' best.[25] This allows a certain degree of "design competition" which spells out itself in the discussions over whether e.g. digitalization or directional instruments is the best path to pursue.[26]

A second consequence of this ambiguity is a reluctance to risk too much on far-reaching R&D projects. With a double-degree uncertainty (not only must technical obstacles be resolve, but there is no guarantee that a successfully completed R&D-project will be well received among users), chances of coming up with *the* solution are very small. Therefore it does not make much sense for individual companies to invest heavily in one out of many possible development projects. It makes more sense to make minor steps, watch what competitors are doing, correct ones own direction according to what seems to be successful, and then take another small step.[27] This seems to a large degree to be the case in the hearing instrument industry. Generally, only when there is a consensus about where to go (and tools are available), development moves fast.

But if there is no such shared understanding regarding the development objectives for hearing instruments in general,[28] there is, though, one aspect about which there is no discussion: The size of the instruments has to come down. There is unanimously support for the position that "the smaller the instrument, the better".[29] This goes for both the ITE and BTE designs, even if one might argue that now some ITE instruments have become so small that they are difficult to handle for users.

This creates a focus on a specific part of the development task, namely the reduction of size, or in short *miniaturization*. While research in the overall question of what is a "good" hearing instrument is still best described as a trial-and error process, miniaturization follows a

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[25] Compare here to e.g. wind turbines: The overwhelming interest of a wind turbine manufacturer is to produce a turbine with a high energy production per investment cost (for the buyer of the turbine). This is a much more well-defined development (one-dimensional) task than in hearing instruments, which are more alike automobile in this aspect. In fact, Lyregaard (1993, pp. 40-41) lists eight performance criteria for a hearing instrument. To develop a better hearing instrument, the manufacturer must strike a balance between all eight performance dimensions.

[26] It is, thus, possible to identify slightly diverging strategies for the manufacturers: For instance, Phonak emphasizes the directional hearing instrument, and Widex and Oticon seek improved signal processing and amplification by going digital.

[27] This strategy makes sense even more since patent protection generally is not efficient for hearing instruments. A complex system (a car or an electronic instrument) is seldom patentable, even though parts (components) may well be. This is the case for hearing instrument technology also.

[28] Lyregaard (1993) is a nice illustration of the bewilderment among industry participants on which way to go.

[29] This is in a funny way a self-fulfilling prophecy: So concerned about the stigma problem, the industry has interpreted the visibility of a hearing instrument as the major cause of stigma. If only other people could not tell who are wearing hearing instruments, there would be no stigma problems. Therefore, a major feature of most brochures for hearing instruments is an emphasis on the product's "tinyness" or invisibility. Thus, even if the customers did not share this view before, as soon as they visit a dispenser they are lured into the understanding that hearing instruments should not be visible, thereby underscoring the stigma problem.

different logic. Guiding this research and development is a *technological trajectory* (Dosi, 1982), mental guidelines shared by all members in the industry that focus attention on a limited number of problems and solutions. While size is only one out of a whole range of features of a hearing instruments, size reduction has been an overarching development pursuit, drawing attention away from other development objectives. Assuming that customers always prefer a smaller instrument to a bigger, also when quality is not the best, the industry has been remarkably successful in making small instruments.

So the overall development of the features of a hearing instrument has not been dramatic over the past couple of decades. A hearing instrument still consists of the same basic types of components, arranged basically the same way, nowadays only added a microprocessor either controlling the analog signal processing or integrated in a digital signal processor. The performance of a hearing instrument has improved, but not profoundly. But the size of the instruments have decreased dramatically. We shall now dwell more specifically on the economic mechanisms behind this achievement.

Systemic technology

Returning to the technological problems of hearing instrument development, it is important to underline another consequence of limited space. Even though the number of components in a hearing instrument is limited, the interaction between these components is highly complicated because of the limited space available. Each component needs to be adapted to each and everyone of the other components, not only to optimize the total system of a set of specific components in general, but also to optimize a system of these components in a spatially specific combination, that is, in a specific layout in a specific case (shell).

The systemic[30] character, the very high degree of interdependency of elements, is therefore pervasive in hearing instrument technology. Integration of technologies (whether components, production techniques or audiological principles) is extremely important. No new technology is of much value *per se* - only after integration with other technologies may it be useful.

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[30] The concept of "systemic" technology has been gaining interest during the 1980s. Rosenberg (1982) emphasized the complementarity between the individual elements of systemic innovations, Winter (1987) mentions the dichotomy between independent and systemic in an attempt to identify dimensions of knowledge, and finally Teece (1988) introduces systemicness in technology as a factor conducive for vertical integration, a perspective further elaborated on also by Langlois & Robertson (1995). A systems approach on nations is the emerging research field of "national systems of innovation" (Lundvall, 1992; Nelson, 1993)

This feature makes rapid movements difficult. Even if one part of a hearing instrument may be dramatically improved, that part still needs to be integrated into the system, and that process may take some time since basically all other parts of an instrument will be affected. All elements must move together, co-evolve, making technological development smoother. This is a stabilizing factor in the sense that "jumps" based on even radical technological improvements along a single dimension of the complex hearing instrument technology are unlikely.

The result of these characteristics of technology of the product, is a development that has had miniaturization as its main component, added numerous improvements on partial problems, such as the feedback problem, or - with the programmable and digital instruments - automatic adjustments to the sound picture. Notwithstanding the efforts and the introduction of new technologies, the overall performance of the hearing instrument has been largely unchanged over the past 25 years.[31] It is easy to be carried away by the very technical language applied in promotional material for new instruments, and mistake the appraisals of the new generations of products for major improvements. Indeed, hearing instruments have become smaller and technically refined, but - for the user - no major breakthroughs have seemingly taken place. Both the lack of sufficient formal knowledge about hearing (making it unclear in which direction to go) and the systemic character of the instrument (making quick moves difficult) are stabilizing factors, impeding individual hearing instrument firms in developing radically new products.

So the impact of technology on industry structure is to favor incumbents. The systemic nature of the technology requires a broad "architectural" knowledge-base and such knowledge is not available on any market. The only way to obtain this knowledge is to participate in the industry, learning from one's own trial-and-error developments and hopefully also becoming able to decipher competitors' experiences. While in other industries entrants with new product innovations may cause disruption, in this industry the ability to produce product innovations is so closely linked to the learning that takes place by being in the industry that entry on the basis of new products seems unlikely. But to a certain degree the systemic nature of technology is an artefact of the economic organization: The technology may have looked very differently had the industry not been so relatively fragmented, and with such strong suppliers. We therefore turn to the economic organization of the industry.

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[31] We are perfectly aware that this is a somewhat subjective assessment that others may not share. The clue is to agree on what to consider a major improvement. We tend to take the perspective of the user.

7. Economic Organization, Especially in Component Supplying Industries

To the extent that many important components are sourced from component producers, hearing instrument manufacturers may be termed assembling companies. While this is not a fair description in general because the "system-knowledge", that is the ability to integrate components into a workable hearing instrument, resides exclusively with the hearing instrument manufacturers, it is an accurate description if just judged on the basis on which physical components are produced in-house as opposed to those sourced outside.

The degree of backwards vertical integration is indeed rather limited. The only component types which some hearing instrument manufacturers produce partly themselves are some electro-mechanical components and amplifiers. The most decisive components are the transducers, i.e. the microphones and the receivers (loudspeaker). These components are virtually all produced by only two companies: Knowles (US) with a market share of app. 80%, and Microtronic (DK) covering 15-20%.[32] Similar market structures prevail in amplifiers and in electro-mechanical components (trimmer, switches, volume controls).[33]

As we have stressed above, each component interacts with all other components in the small space available inside the shell of a hearing instrument. A component supplier, thus, cannot change a parameter of its component without influencing the functioning of the entire hearing instrument, all else equal. Once a component has been designed into a specific hearing instrument model, it typically will not be substituted by another supplier's components, neither a cheaper one (since even the so-called "drop-in" copies are never exactly the same as the original components) nor a better one (since one better component can rarely improve the performance of a whole instrument), thus establishing switching costs.

The manufacturer is the assembler of diverse components, and is therefore the coordinator of disparate suppliers and their components. Each supplier provides no more than one, small part of a larger whole, characterized by strong technological interdependencies. Therefore, when a supplier develops a new, standard component with a changed functionality, it must obtain acceptance from a range of manufacturers which again has several constituencies (designers, production engineers etc) which all have to be sworn in. Acceptance is slow because

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[32] There are a couple more producers, Lectret (CH/SIN) and Tibbett (US), but they hold very small market shares.
[33] The important companies in amplifiers are RTI (US) and Gennum (CAN); in electromechanical components they are RTI and Microtronic.

the systemic nature of the technology creates large switching costs for hearing instrument manufacturers. Thus, the introduction of a new and superior standard component takes a good deal of coordination.

The development of a standard component aiming at broad acceptance from all manufacturers is, however, only one of two conceivable ways of getting success as a component supplier. Instead of seeking acceptance from many manufacturers, a supplier might bet on only one manufacturer, supplying that particular one with a custom-designed component. This has (hitherto) not been a feasible strategy, however, because development costs are high, and economies of scale in production considerable (making a customized component more expensive than a standard component).

Therefore, suppliers have not only refrained from developing customized components but has also tried to avoid coordination costs by maintaining the same functionality in a component, instead concentrating on making it still smaller and smaller. In short, "make the same but smaller", complying with and buttressing the miniaturization trajectory of the industry. As long as a component's performance is well-known, acceptance of a smaller version is almost guaranteed. This logic has driven component suppliers to develop reduce the size of their particular, discrete components dramatically over the years. Today, a microphone or a loudspeaker is only a couple of millimeters wide, weighing as little as 0.2 grams.

Market structure in transducers

Established in 1946, the American, family-owned Knowles Electronics[34] has ever since been the de-facto standard setting player in the transducer product-market with a market share now of roughly 80%. With this market share, volume production at Knowles has been possible, a crucial requirement for cost-effectiveness in the production of a generic product such as transducers. As a result, Knowles has moved far down the learning curve of transducer development and production.[35] Following our arguments above, Knowles has not engaged in customization of components.

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[34] Business directories estimate the size of Knowles to between 700 and 1,200 employees, with sales between $100 and $200 million.

[35] The Danish hearing instrument manufacturer, Danavox, produced transducers in-house at some point in time. It is well-known in the industry that Knowles bought the production equipment and destroyed it.

A further factor reinforcing the position of Knowles is the strong appropriability regime prevailing within transducers (as opposed to the hearing instrument as such). Patents are effective and frequently used because the parameters of transducers can be explicitly specified. Knowles has an impressive and highly effective patent profile. Its closest competitor, formerly Microtel now Microtronic, has historically positioned itself in the market for transducers by engineering "around" these patents to deliver so-called "drop-in" replacements of Knowles' products, as this was seen as the most sound way of getting a foot-hold in the market for transducers. Microtronic is now attempting to change this follower-strategy and has successfully launched its first, non-Knowles-alike product.

Knowles is thus in a virtuous circle, continuously cementing its own position and making entry or development of alternative suppliers' position extremely difficult. Although it is virtuous for Knowles, it might be frustrating for hearing instrument manufacturers as they are not accommodated in their requests for special components and as Knowles' bargaining power is maintained at a high level.[36]

There has been only few attempts to challenge Knowles. In 1989 Siemens Audiologische Technik purchased the independent Dutch transducer supplier Microtel. As mentioned, Microtel developed and produced "drop-in" replacements of Knowles' products in order to reduce switching costs for hearing instrument manufacturers. However, in transducer production economies of scale are pervasive, and high volumes are necessary for profitable operations. In-house demand from Siemens itself could not establish sufficient volume in Microtel, and Siemens' competitors were reluctant to purchase transducers from Microtel due to confidentiality and lock-in concerns *vis-à-vis* Siemens. Therefore, in 1993 an exclusive sales agreement allowed Microtronic to sell its own electro-mechanical components and Microtel's transducers at the same time. And in 1995, Microtronic acquired Microtel. Since then, Microtronic has developed as a small alternative supplier to Knowles.

In general, the lack of vertical integration between transducer suppliers and manufacturers can be explained by the scale economies in development and production of the component. No single hearing instrument manufacturer can live up to volume requirements for

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[36] Knowles' position in the hearing instrument industry may be compared to the position of Intel and Microsoft in the PC industry. In the PC-industry, the lion's share of profits end up with the two major suppliers, Microsoft and Intel, while the producers of PCs - to be compared with the hearing instrument producers - earn only a modest part of total profits. See Borrus & Zysman (1997) for an analysis of the PC industry with this perspective.

minimum efficient scale (MES) of production. And as the competencies needed for transducer production are so different from hearing instrument production, economies of scope in R&D and production are virtually non-existing.

Therefore, the vertical integration of Siemens in 1989 could not break Knowles' monopoly, and it remains to be seen whether the uprising of Microtronic will serve as a significant challenge for this. In this respect, the behavior of the hearing instruments manufacturers could be of significant importance. If manufacturers actually feel exploited by Knowles, they in principle could just shift to Microtronic (if not immediately, then gradually) and establish a balance of power between the two suppliers. However, as long as Knowles still has a cost and product-breadth advantage compared to Microtronic, such a move is initially costly for each manufacturer.[37] So while concerted action would be to the benefit of all manufacturers, each of them would rather let the others pay the price and keep buying from Knowles; a classical Prisoners' Dilemma. And despite manufacturers' successful cooperation in other fields,[38] there seems to be no successful coordination of support for the alternative supplier.

Conclusion

It is always tempting to take technology as exogenous, and trace the influence of technology on economic phenomena. This is what research on innovations and entry does, and this is what we have done in the our analysis of the nature of technology in hearing instrument (section 6). After that, we turned around (in section 7) and asked the question, How does this "nature of technology" fit with the industrial structure? We interpret the relationship as one mutually reinforcing fundamental characteristics of both sides, technology and industrial structure: The systemic technology with many separate, but interdependent components allows a concentrated supplier structure, which again hinders an change in overall technology. Or put it differently, technology is embedded in industrial structure as much as the structure is a product of the nature of technology. But whereas technology and economic organization is intertwined, there is no guarantee that this particular relationship will not break down. Let us spell out these points in some detail.

[37] Of course, if the manufacturers have any leverage at all, they should assess carefully the trade-off between being exploited by a monopolist with major cost advantages due to scale economies, and buying from two competing companies, each of them with no chance of matching a monopolist's scale economies. The choice hinges on the degree of scale economies and the degree of competition between two possible suppliers.

[38] See Lee & Lotz (1998).

The very limited number of component suppliers may well limit possibilities for turbulence among hearing instrument manufacturers simply because all manufacturers will have to use the same suppliers and basically the same, generic components. The manufacturers may not like this situation: In order to be able to distinguish themselves from the other manufacturers, each manufacturer seeks to introduce new products with superior and distinctive features. But to make a really different new hearing instruments that cannot be imitated immediately, the manufacturer would need customized components. However, as long as component suppliers are not forced (by tough competitors) into this business of customizing, they probably will prefer to produce as standardized components as possible. By doing so, they not only obtain the best short run protection of their market power, they also avoid the risk that one hearing instrument manufacturer - by introducing a successful instrument based on a customized component - should gain so much market share that captive production of components would be economical. (Had Siemens had a 50% market share, in-house production of transducers might have been feasible.) So obviously, component suppliers have a strong interest in keeping their customer base - the hearing instrument industry - fragmented, and one way of doing this is by insisting on standard products.

As long as the hearing instrument manufacturers are not in a position to produce their own components (at least not all of them, and especially not the transducers, as we have seen), the manufacturers must rely on the components from suppliers. In a sense, this deadlocks important dimensions of technological development in the industry, because the manufacturers cannot internalize the entire technological system and optimize over all components.[39] And a component supplier cannot enter the manufacturing business (forward integration) alone; only if a range of component suppliers covering all component types go together they may succeed.

Will this continue? Not necessarily. A concentration in the manufacturer industry - caused e.g. by a major merger - may allow one or more big hearing instrument manufacturers to invest in in-house production of components, partly in order to escape Knowles' market power, and partly to be able to integrate technologies that hitherto has been brought together from

[39] We here see an example of the limits of the argument (e.g. Figueiredo & Teece, 1996) for vertical integration because of systemic technology. If economies of scale are sufficiently strong in some elements of the product, and the industry using these components is sufficiently fragmented, vertical integration of these elements may be impossible.

several sources. In case they succeed, the entire industry structure and the very nature of technology may very well change dramatically.

In the short run, however, manufacturers are caught in a structure that does not allow them to make major breaks from the ongoing technological development. The lack of control over important parts of the technology limits their chances of breakthroughs in technology. And entry from outside is highly unlikely, except if some company finds a proprietary substituting technology that replaces the entire technological system which now makes up a hearing instrument. And even in that case, knowledge about hearing and access to distribution may be competencies without which a new comer cannot succeed.

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