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INNOVATION AND DOMINANT DESIGN

IN MOBILE TELEPHONY***

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ABSTRACT: We document the evolution of product innovation and features in the mobile telephone handset market. We distinguish between two types of product innovation: vertical and horizontal innovation. Using data from 1990 - 2003, we find that some characteristics have subsequently become an industry standard, while some remained as horizontally differentiating features of mobile handsets. We explain this pattern using the concept of dominant design, and results from the theoretical literature on the incentives for horizontal and vertical differentiation.

Keywords: Product innovation, mobile phone handsets, dominant design, min-max principle.

JEL Codes: L15, L96, O32

1. Background

Product innovation in the global mobile phone market has followed a clear pattern. Innovations on the system level (e.g. infrastructure, technological standards) were followed by rapid innovation in various technological components enabling more user-friendly product characteristics such as lower weight and longer talk time. As innovations surrounding these characteristics stagnated, a flurry of additional features (e.g. games, ringtones) was introduced. Some of the innovations became a quasi-standard, or dominant design, while some remained as horizontally differentiating features of mobile handsets. Exploring and explaining this pattern is the main aim of our paper.

Emerging technologies pass through several stages before they mature. Typically, a *radical (or system) innovation* or *technological discontinuity* marks the onset of a new technology; it is "based on a different set of engineering and scientific principles and often opens up whole new markets and potential applications" (Henderson and Clark, 1990). Firms will introduce alternative designs until some design combination becomes clearly preferred by end-users and forms a *dominant design*, a (product and/or process) *architecture that becomes widely accepted as the industry standard* (Anderson and Tushman, 1990).[1] Following the establishment of a dominant design, a number of *incremental innovations* will typically be introduced until the technology has fully matured.

The process of finding a dominant design is closely linked to the study of standardization which examines the process by which products in a market converge on

[1] We do not consider process innovation here. While on a theoretical level the arguments for incentives to innovate on the product or process level are very similar (Tirole, 1988), process innovations are difficult to identify in most available datasets and thus difficult to measure. However, Filson (2002) uses detailed industry-level data to track patterns of product and process innovation in the computer industry, and Rosenkranz (2003) develops a theoretical model with both types of innovation.

a design, or standard, that ensures that all products are interoperable, or compatible.[2] This literature distinguishes between *de jure*, or mandated, standardization and *de facto*, or market-driven, standardization. In many ways, *de facto* standardization is akin to the (unregulated) process of finding a dominant design. Another way to establish a dominant design is a *formal or coordinated standardization* procedure. The design may then be determined either by public bodies (e.g. by ministries or regulators) or collaboratively within standardization consortia usually comprising experts from standardization organizations and industry participants. Standards may also be developed via direct negotiation among the leading firms (e.g. NMT technology in the Nordic countries) or via firm collaboration through private alliances (Axelrod et al., 1995, Leiponen, 2004, Kretschmer and Mühlfeld, 2004).

Producers and users face considerable uncertainty until a dominant design emerges or an industry standard is created. This uncertainty subsides once one of the technologies (or designs) emerges as superior and becomes widely used. Firms then focus their resources on incremental technical change within the established dominant design, further reinforcing its dominance. The level of analysis chosen by the *researcher* or observer generally defines the distinction between dominant design and incremental innovation. Various scholars have focused on dominant designs at the product level (e.g. Geroski, 2003), whereas others have analyzed dominant designs on product subsystems (e.g., Henderson and Clark, 1990). Our analysis focuses on the evolution of dominant design on cellular handset design and features. The design and features that become a dominant design form a dominant design at the product level, i.e. a dominant design handset model.

[2] Koski and Kretschmer (2004) present a survey of the recent empirical literature on network industries.

The dominant handset features arise primarily from two generic product development strategies available for firms. Firms may i) differentiate their products vertically by developing the current product technology or its characteristics (i.e. produce vertical innovation) or ii) horizontally by introducing additional product characteristics (i.e. produce horizontal innovation). V*ertical innovation* (*VI*) establishes a clear quality ranking in the eyes of all consumers; a better product is the one with better individual characteristics. Assuming equal prices therefore, all buyers would choose a product with the attribute(s) of higher "quality" (e.g., a computer with a faster processor). *Horizontal innovation* (*HI*) is less straightforward in its implications for consumer preferences; two products with different added product features (e.g. different styles and colors) appeal to different consumer groups. That is, a specific horizontal innovation will increase the willingness to pay only for some consumers. With horizontal innovations however the principle of "more is better" also applies: Given equal prices, a product *with* a particular feature is better than the same product *without*. Strictly speaking then, both types of innovation are vertical in the sense of Shaked and Sutton (1982). In our paper however, we follow the nomenclature used in several EU publications on innovation: "*Vertical innovation takes place where all customers consider a product has been improved at the same price, whereas horizontal innovation occurs where only some customers regard a product as improved*".[3] Horizontal and vertical innovations that are *imitated* widely by competitors form a dominant design.

We present a systematic analysis of the phases of product innovation in the global mobile handset market.[4] We do not consider here the development of international cellular telephony standards for radio access and transmission from 1G to 3G

[3] See, e.g., http://aoi.cordis.lu/print_version.cfm?article=1115

[4] See also Lehrer (2004) for a discussion on the role of national lead markets in formation of dominant design on the market for 3G network applications.

technologies (i.e. mobile communications network standards)[5] that was a sequence of radical innovations guided both by mandated standards and laissez-faire standardization varying across countries and technological generations (see Gandal et al., 2003, Koski and Kretschmer, 2005, and Leiponen, 2004, for a discussion on standardization in the mobile telephony market). In 2005, GSM dominated the world's wireless market having over 1.3 billion users and almost a three quarters share of the total market.[6] Our data show that between 1992 and 2002, GSM was also the technology most commonly supported by new handset models: about 40% of new handset models were GSM compatible. The market for 3G wireless telephony is still at a relatively early stage; so far, 3G cellular phones have not (yet) overtaken GSM phones.

A few words on the distinction between technical and user-focused innovation. Judging the *degree* of an innovation, i.e. whether an innovation should be classed as radical or incremental, is difficult when examining innovations in the user interface (UI) of cellular handsets[7]. For example, a radically new display technology may not be considered a great improvement for users who will not spot a major difference. Instead of trying to survey the timing and adoption of individual technological breakthroughs (such as lithium batteries) therefore, we look at *innovation* in handsets *from the user's point of view*. For example, we consider changes in talk and standby time and the weight of handsets rather than the changes in battery technology that make such improvements possible. We find this approach attractive since a typical mobile phone

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5 Worldwide there were eight analogue or 1G handset standards, four 2G digital cellular standards (CDMA, GSM, PDC and US-TDMA), and three 3G standards (CDMA2000, TD-SCDMA and W-CDMA or UMTS) defining the division of frequency spectrum into radio channels and user allocation within them.

6 http://www.gsmworld.com/news/statistics/index.shtml

7 Products generally have multiple nested subsystems differing in their degree of centrality. The core subsystems of products - i.e. those subsystems of which changes have a greater system-wide effect than changes in peripheral subsystems - may also shift over time (Tushman and Murmann, 1998). This is typical for the development of complex products for which the main challenge is systems integration through continuous advances in subsystem level solutions. Innovation is often centered around core subsystems that eventually reach a sufficient level of performance or close in on a dominant design, shifting focus on the development of erstwhile peripheral subsystems.

user is likely to be more interested in the features and capabilities of a handset he buys than its technological details. Moreover, we investigate the development of product characteristics for the user interface (UI) and additional (user-oriented) features of cellular handsets.

We use a comprehensive dataset comprising information on all mobile phone handsets[8] introduced globally between October 1991 and the end of the year 2003 to document the evolution of handset designs.[9] We then use a subset of the sample comprising handsets introduced between 1996 and 2002 for which detailed information on product features was available to track some of the innovations in product features that have taken place. We identify two phases of technological competition: i) the era of weight and size competition resulting in major technological improvements and vertical product homogenization and ii) the era of introducing additional handset features (or horizontal innovation) related to increased product differentiation. We also find that that imitation of product features appears relatively simple (since many of the product innovations we track are imitated rapidly), yet firms are still introducing new product features frequently.

The paper is structured as follows. We pose and discuss the two pertinent questions of our paper in Section 2. Section 3 illustrates the phases of innovation and competition in mobile handset production using this framework as a guideline in exploring our dataset on new mobile telephone models. Section 4 discusses some possible explanations for the observed innovation pattern, and Section 5 concludes.

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[8] Our definition of a mobile handset covers traditional wireless handsets and smartphones, i.e. wireless telephones that have certain advanced (computer-enabled) features (they may, e.g., allow wireless e-mail or Internet use).

[9] Our data is compiled from the EMC World Cellular Database comprising all new mobile handset models launched since 1991.

2. Some pertinent questions on innovation in emerging industries

Firms developing a technology have to allocate their research resources on one (or more) of the following fields: First, firms can develop and improve a product's core technology and improve existing product features through technological progress. We call this *vertical* innovation. Second, new product features can be introduced, which we call *horizontal* innovation. If innovations were random and firms directed the same effort into each of these, we would expect a mixture of innovations of each type at any one time. As firms will spend most funds on the activities with the highest marginal productivity however (Milgrom and Roberts, 1992), we expect, perhaps somewhat obviously, innovation to take place in the most profitable fields. Firms may differentiate their products vertically and horizontally (at least temporarily) via vertical and horizontal innovation but often imitators adopt innovations and, if innovation is commercially successful and widely adopted, it may form a dominant design as all products in the market offer this technology or design feature.

There are plenty of questions one might ask about innovation in an emerging technology. In this paper, we focus mainly on issues surrounding the sequence and types of innovations over time, and the contribution of product innovation to the formation of a dominant design. In particular, we ask the following questions:

- *How does the type of innovations change over the lifecycle of a technology?* We distinguish between different types of innovation - vertical and horizontal innovation. It will be interesting to see if there is a specific ordering to these (product) innovations over the technological lifecycle in the industry similar to the switch from product to process innovations (Filson, 2002). In particular, asking if, e.g. vertical innovations come mainly before settling on a dominant

design and horizontal ones set in after a dominant design has been found could suggest a general pattern of innovations that may be repeated in different product generations or industries. This resonates with Tushman and Murmann (1998), who find that despite settling on a dominant design, innovation still occurs, albeit of a different character.

- *Which innovations form part of the dominant design?* This equates to asking which innovations get imitated by followers to the extent that all new products become homogenous in respect to these innovations (Anderson and Tushman, 1990, Henderson and Clark, 1990). Imitation can be said to have two main effects: First, it intensifies competition since products are more similar. Second, it increases demand because the quality of the imitating product has improved.[10] If imitation is simple and feasible, the balance of these two effects will determine whether a particular product characteristic will become a dominant design (if it is too costly not to innovate) or a source of horizontal differentiation (if competition would become significantly more intense if it were imitated) and if the theoretical prediction of minimal differentiation in some, but maximum differentiation in other dimensions (max-min) holds (Neven and Thisse, 1990, Vandenbosch and Weinberg, 1995).

We seek to find answers to these two questions and their interactions. By tracking innovations and their type over time we should be able to identify a pattern in the matrix drawn up in Figure 1 that gives examples of vertical and horizontal innovations that have created a dominant design and that have led to competition between differentiated versions of innovation (or innovative feature). For example, if vertical innovations mainly form the dominant design and differentiation happens in horizontal innovations,

[10] For an application of this to the banking industry, see Degryse (1996).

the main diagonal cells should contain more entries than those of secondary diagonal cells.[11] If, on the other hand, successful innovations are random, we would expect innovations to be distributed evenly across cells.

Figure 1. Types of innovation and contribution to dominant design.

Innovation type	Dominant design	Differentiation
Vertical innovation	Game Consoles: 64bit capability	Microprocessors: Clock speed
Horizontal innovation	PC Operating Systems: Internet connectivity	Fixed-line telephony: Cordless handsets

Our paper is exploratory rather than explanatory - we are not claiming to irrefutably explain why certain patterns occur. Our data (explained in more detail in Appendix 1) does not allow for calculations of expected profitability and therefore marginal benefits of a given innovation, but we nevertheless believe that identifying patterns relating to our two questions (in Section 3) and offering some possible explanations (in Section 4) will shed some light on the nature of innovation and technological competition in the mobile telephony market.

[11] The main diagonal cells are those that run from the upper left entry to the lower right entry, whereas secondary diagonal cells run from the lower left entry to the upper right entry.

3. Dominant design and innovation in mobile telephony

3.1 The era of weight and size competition

Manufacturers of digital mobile phones competed "*principally on the basis of price, size and battery lifetime*"[12] up to the mid-1990s. Bigger and better batteries meant larger and heavier (and more expensive) mobile phones, but they had longer run-time than smaller ones. The design choices were thus governed by the trade-offs between production costs, size and weight and battery run-time.

Figure 2. The development of wireless handset models: average weight, talk and standby times, 1991-2003

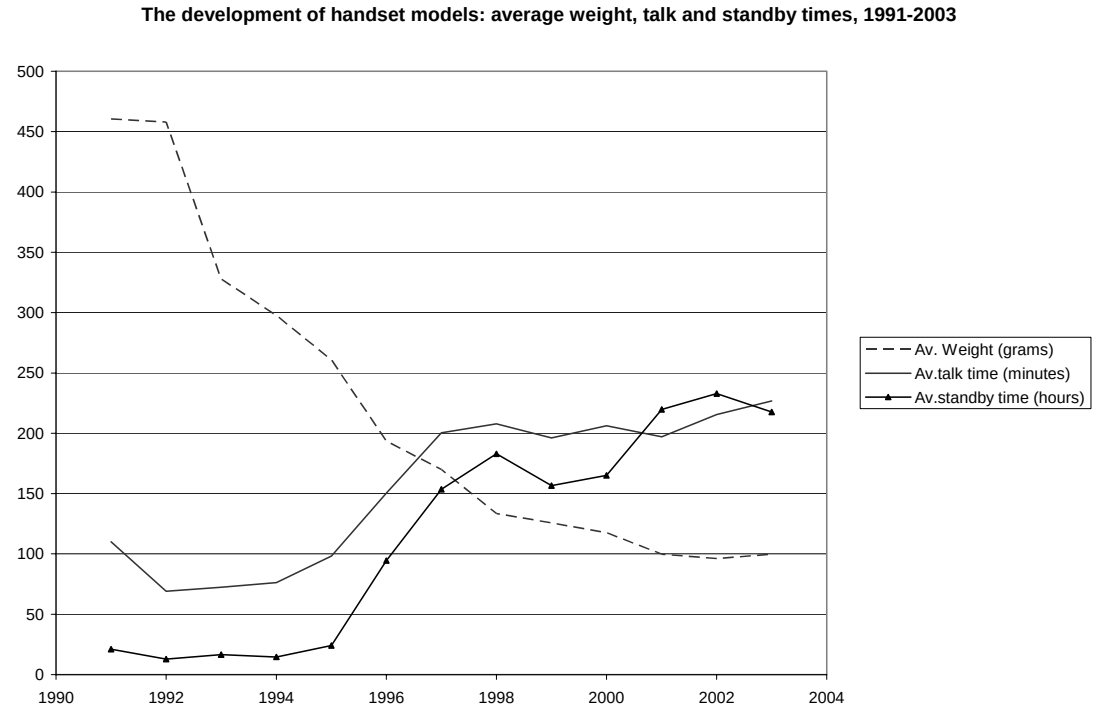


Figure 2 reflects the development of wireless handset models in terms of weight, and talk and standby[13] times from 1991 to 2003. The first mobile handsets were relatively heavy; in the early 1990s, the average weight of a handset was close to 500 grams. Talk

12 Source: *Design Engineering*, Jan 97, p.11.

13 Standby time is the time that the battery of a phone lasts when the phone is turned on but not in use.

and standby times were also moderate: an average mobile phone allowed a user to talk for not much more than an hour and to have the mobile phone on standby for less than one day before the battery had to be re-charged.[14] During the 1990s, technological progress in wireless telephony was fast, and soon mobile phone users were carrying substantially lighter equipment. In 2001, the average weight of new handsets was less than 100 grams. Technical improvements - particularly Sony's commercialization of rechargeable lithium ion batteries in 1991 - not only enabled lighter cellular handsets but also resulted in a notable increase in talk and standby times. New handset models introduced after the mid-1990s had an average talk time of about 200 hours and standby time greater than 9 days. Figure 2 and Table 1 illustrate that the drastic technical improvements in wireless handsets occurred simultaneously with the peak period of new model introduction.

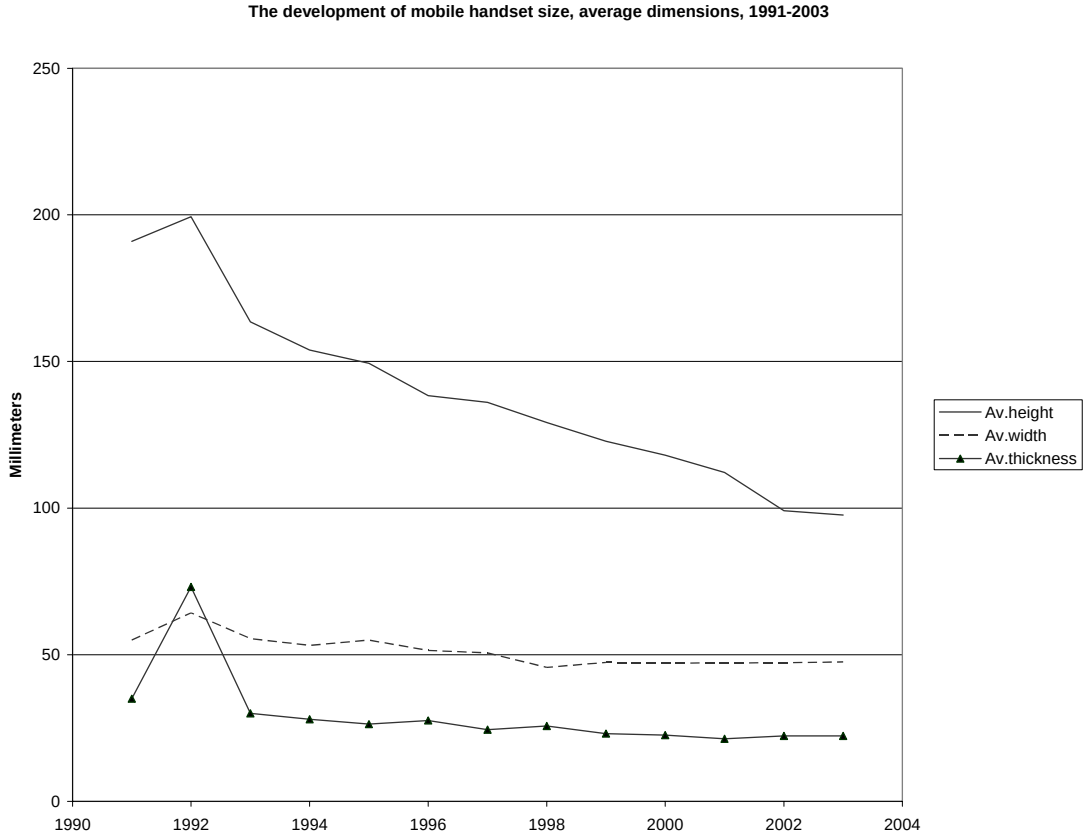
Table 1: New handset introductions and entrants, 1992-2003.

Year	Number of new firms launching new handset	Number of new handset models
1992	3	7
1993	2	4
1994	9	28
1995	15	99
1996	14	362
1997	10	371
1998	6	349
1999	2	256
2000	3	241
2001	9	358
2002	7	242
2003	10	402

[14] This may not have been such an important restriction then since most analogue mobile telephones were mounted in cars with access to the car battery. However, this also limited the diffusion of 1G mobile telephony (Liikanen et al., 2004).

Figure 3 illustrates the development of mobile handset designs regarding height, width and thickness of new handsets (all measured in millimeters). There is a general trend towards smaller mobile phones, but the changes in the width and thickness of the new models have been less dramatic than in their height. In 2002, the average handset height was about 10 centimeters, about half of the average height of models a decade earlier. From 1991 to 2003, the average width decreased by 14% (from 5.5cm to 4.7cm) and the average thickness by almost 40% (from 3.5cm to 2.2cm), respectively.

Figure 3. The development of mobile handset design, average dimensions, 1991-2003



Figures 2 and 3 illustrate patterns of development in wireless telephone technology and design but they do not tell much about variations in the model technology and design at any given time, i.e. whether manufacturers have launched increasingly differentiated or homogenous handsets. Weight, talk and standby times are vertical product attributes:

users agree that lighter handset models or handsets with more talk and standby time are better. Development of and differences in these features therefore refer thus to *vertical product differentiation*. On the other hand, consumers will probably have some differences in their preferences concerning the handset size. For example, smaller phones often tend to be difficult to use and come with a smaller screen.[15] Therefore, height, width and thickness are best referred to as *horizontally differentiated* product features. We use the coefficient of variation (CV)[16] of handset attributes to explore changes in the heterogeneity of the new mobile handset model mix over time.

The calculation of the (annual) coefficient of variation for the weight, and talk and standby times of handsets shows that handset heterogeneity has clearly increased in the first half of the 1990s, but has constantly decreased thereafter (Figure 4). It seems that during the years 1995-1996, mobile handset manufacturers introduced new models with hugely different weights, talk and standby times,[17] but that thereafter, convergence towards lighter handset versions with longer talk and standby times was rapid.[18] In other words, since the mid 1990s, mobile phones have become increasingly homogeneous regarding their technical quality and weight.

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[15] This problem has been alleviated somewhat by the recent hugely successful introduction of the "clamshell" design, where the surface (or workable) area of the phone is essentially doubled by having the screen on one side of the shell and the keys on the other.

[16] CV is calculated by dividing the standard deviation of weight (talk/standby time) of new handsets divided by their mean weight (talk/standby time) each year.

[17] For instance, in 1995, the shortest standby time of new mobile phones was only 6 hours, whereas the longest standby time was more than 20 times longer, 125 hours.

[18] This strong heterogeneity seems to be down, at least in some part, to the large number of models introduced by new firms. We will come back to this argument in Section 4.

Figure 4. The coefficient of variation for the weight, talk and standby times of wireless handsets

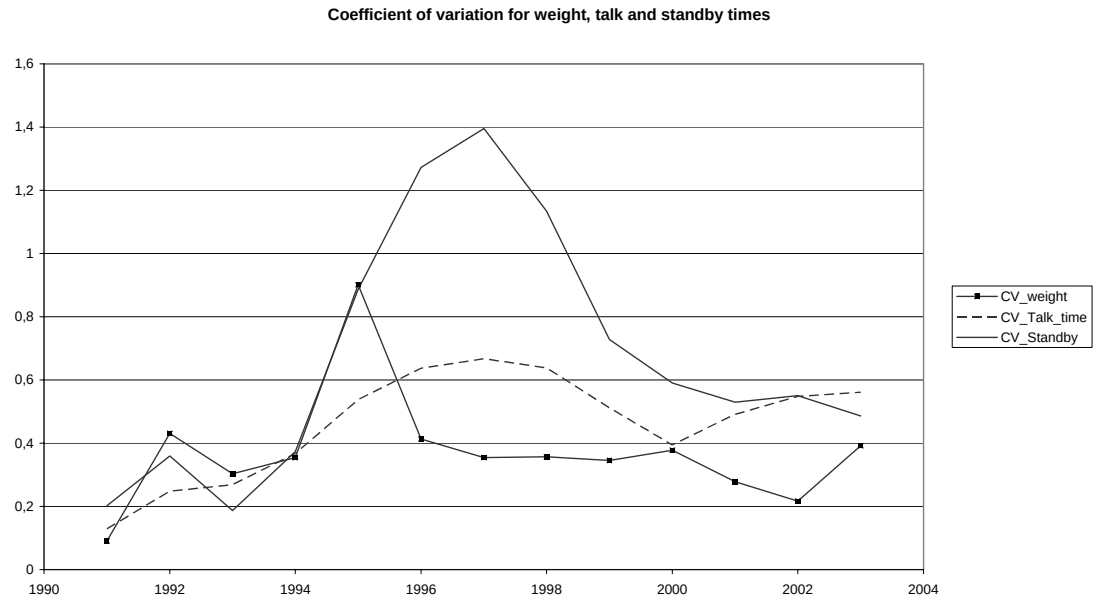
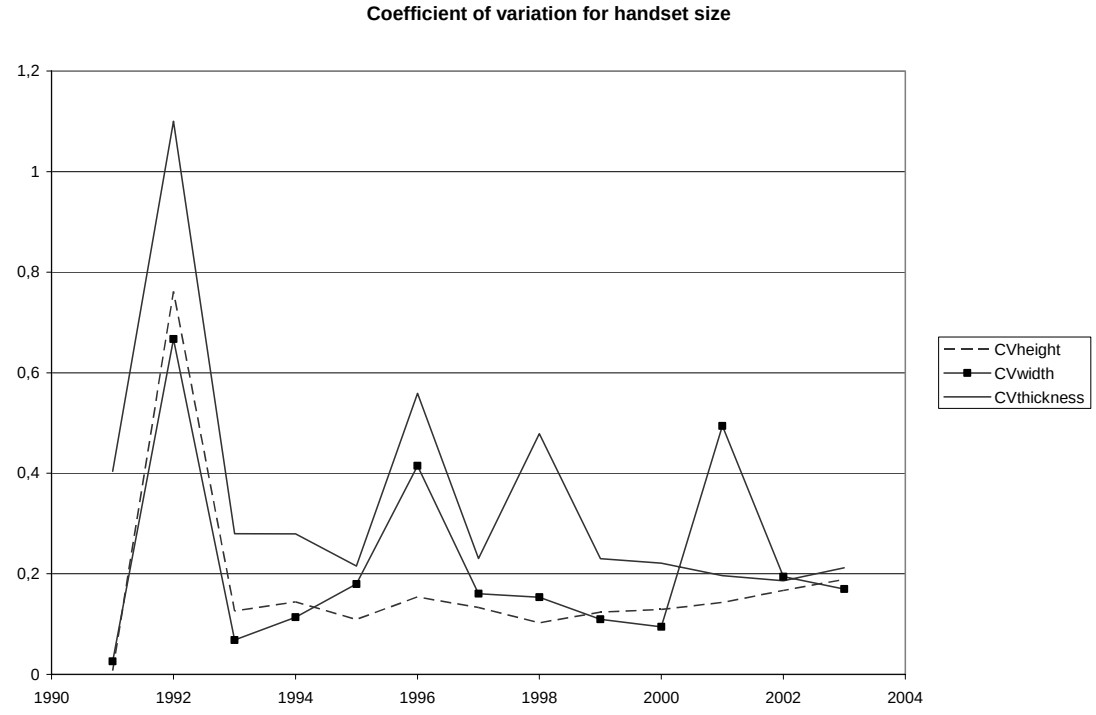


Figure 5 shows that the size of mobile handset models developed differently. Height converged to a typical value of around 11-12 centimeters quite quickly, while the variation of width and thickness has been changing quite drastically over time.

Figure 5. The coefficient of variation for handset dimensions



Our data shows that since the mid 1990s, there has been a clear and quite smooth convergence towards light, compact mobile handset models with improved technological performance; new handset models introduced each year have become increasingly homogenous in terms of their technical performance and weight. In other words, there has been a trend towards *vertical product homogenization*. Conversely, the size of new handset models has converged neither as dramatically nor as smoothly in our ten-year period of observation. However, as the coefficient of variation has been comparatively lower for the dimensions of size than that of technical performance, we conclude that mobile handsets have been more heterogeneous, i.e. more vertically differentiated in terms of technical quality or performance than in terms of size.

3.2 The era of customer segmentation and product differentiation: user interface and advanced features

Innovations at the subsystem level or incremental technological change increase the performance of a new technology but may not provide a long-lasting competitive advantage for the leaders, especially if they are easily imitated. To succeed at this stage, firms have to gain a technical advantage combined with successful product differentiation and marketing strategies. Product differentiation often takes place through the addition of new features and functions or product design, and as different firms often serve different segments of markets or niches of consumers, it also lessens price competition.

For mobile phone manufacturers, the design of the user interface - i.e. the system of components that allow users to interact with the mobile phone - can determine not only the success of an individual model but also that of subsequent models launched by the company since the “look and feel” of phones frequently stays the same over several generations.

Unlike for PCs, there is no standard user interface in the mobile industry.[19] None of the manufacturers has succeeded in creating a dominant user interface although some user interface features such as the alphanumeric keypad layout (recommended by International Telecommunications Union, ITU) are applied widely and some of them such as the Navi-key[20] (introduced by Nokia in 1997) are close to ubiquitous in new handsets (Kiljander and Järnström, 2003).

The end of the era of miniaturization brought new challenges for handset designers: "*Smaller, lighter, faster won't do it anymore*."[21] New strategies were needed to attract new customers and, as the market in industrialized countries matured, stimulate replacement demand from existing users. Customer segmentation and product differentiation became increasingly important strategic tools for manufacturers. Additional features to voice services such as color displays, games, multimedia messaging and cameras became the new focus of cellular handset design. For designers, product differentiation meant a growing number of handset attributes, introducing a new trade-off, this time between increasingly sophisticated features and battery life-time and processing power. Also, the importance of user interface design in manufacturer strategies was emphasized when design required the simultaneous inclusion of multiple advanced features.

The manufacturers' choice of additional features represents horizontal differentiation as users will value certain product characteristics differently (e.g. some users value games

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[19] One might argue that this has not been of paramount importance until recently. Now that mobile telephones converge increasingly with other devices such as hand-held computers, an increasing trend in the industry goes towards a common user interface (UI) across all devices. An alliance of operators has started pushing for an open standard, the Open Mobile Terminals Platform (OMTP) to "…provide customers with a more consistent and improved users experience by delivering openly available […] interfaces." Such a move would obviously reduce switching costs among handsets by different manufacturers.

[20] Navi-key is the one-softkey user interface that provides one-button access to the (catalogue of) functions of the mobile phone. The Navi-key for a mobile phone is basically the same as a mouse for a personal computer

[21] *RCR Wireless News*, 2000, Vol 19, Issue 40, p.37.

higher than multimedia messaging and vice versa). We divide additional features into four categories: i) voice communications, ii) data communications, iii) design and iv) additional functions. Unfortunately, our data on additional features covers only part of the new handset models launched between 1996 and 2002 (see Appendix 1 for a further description of the data).

i) Voice communications features

We track three features that add value to wireless voice communications: speed dialing (i.e. a user can dial a phone number by pressing one key), vibration alert (i.e. the user can choose a silent (or vibrating) alert for incoming calls) and memory locations (i.e. the number of phonebook entries that can be saved in the memory of a handset). Most handset models had a speed dialing option throughout the observed time period 1996-2002. Vibration alert, available in all sampled models in 2002, was not very common in the new handset models after the mid 1990s - only about 30 % of the sampled models offered vibration alert option. The average number of memory locations has increased more than threefold, from less than 100 to more than 300, during the same time period.

Figure 6. The coefficient of variation for voice communications features

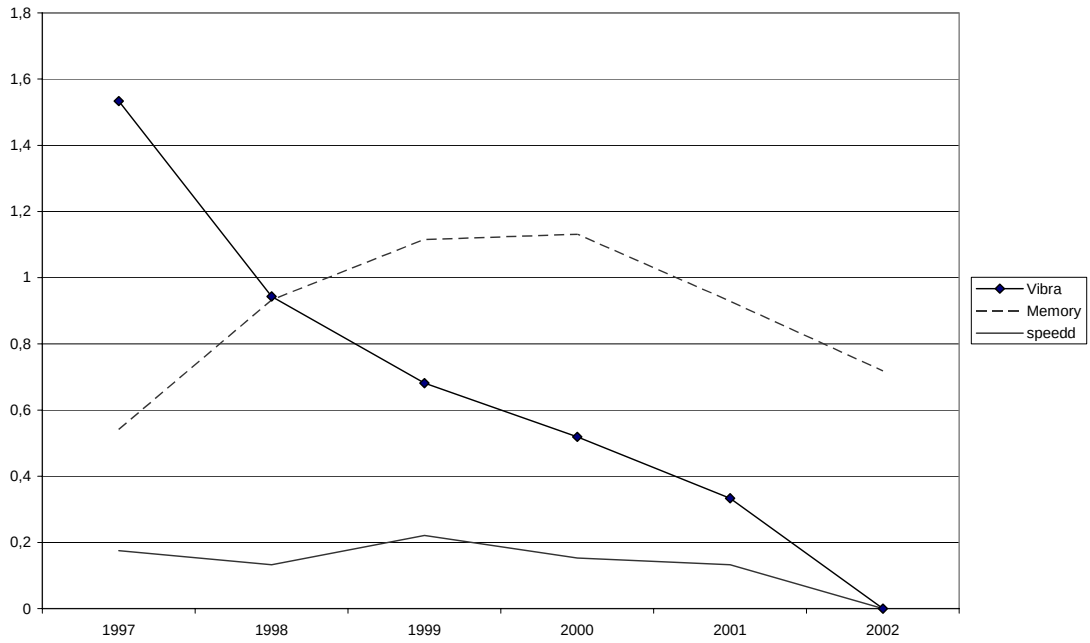


Figure 6 shows that cellular phones have become homogenous in terms of the vibration alert option and, although they have converged slightly in terms of the number of memory locations, in 2002 there was still considerable variation among new cellular handsets in this respect. Differentiation was relatively weak with regard to the speed dialing option already in 1997 and by 2002 it had vanished (i.e. all (sampled) handset models provided speed dialing).

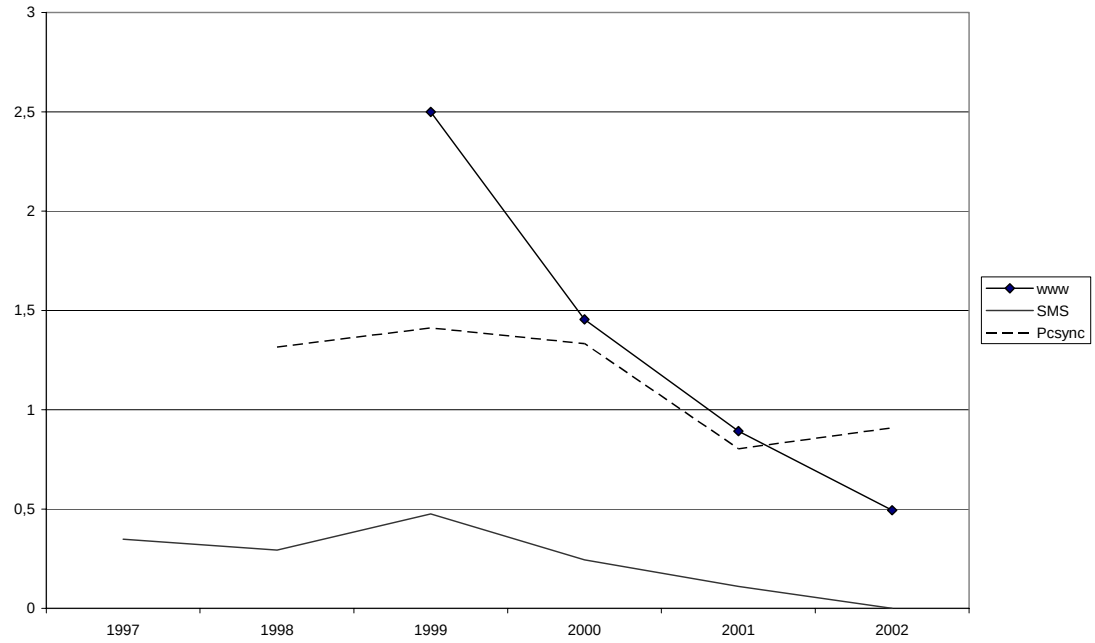
ii) Data communications features

Data communications features are captured by the SMS or Short Message Service function, WWW capability, and PC synchronization. SMS provides the simplest form of wireless data communications: sending and receiving text messages with a maximum length of 160 characters.[22] PC synchronization means that a user can connect a cell phone to a computer with a cable and transfer data (e.g. for transferring contact information between e-mail system and mobile phone). The WWW, or WAP, function extends data service options of a handset to cover web browsing. In 1996, none of the models in our sample had enabled web browsing or PC synchronization but most of them already supported SMS.

By 2002, all new models offered text messaging (see Figure 7). The coefficient of variation indicates that in the late 1990s, new handset models were quite varied in terms of the WWW and PC synchronization options. New handset models have rapidly converged in providing web access and somewhat less dramatically in offering PC synchronization. However, heterogeneity in regard to WWW and PC synchronization remains relatively high.

[22] This feature is one of the success stories in telecommunications. SMS made owning and using a mobile phone attractive to a previously untapped major segment of the market, teenagers and young adults. According to Forrester Research, in 2002 SMS revenues accounted for 12 % of European mobile operators' revenues (www.forrester.com).

Figure 7. The coefficient of variation for data communications features



iii) Design features

Our data covers two design features: the number of colours with which a new handset model is produced and the number of ringtones (i.e. different melodies stored in a phone). Though the average number of ringtones in new cellular handsets has increased from less than 10 to more than 30 between the years 1997 and 2002, the CV for these features has remained relatively stable (see Figure 8). The CV for handset colours has been even higher, and it has not displayed any major decline during the years 1997-2002.[23]

[23] This may be related to manufacturers strategies of selling shells ex-post and the emergence of an independent market for mobile phone shells. This would then however raise the question as to why manufacturers offer any choice in the first place if any number and style of replacement shells can be bought afterwards.

Figure 8. The coefficient of variation for design features

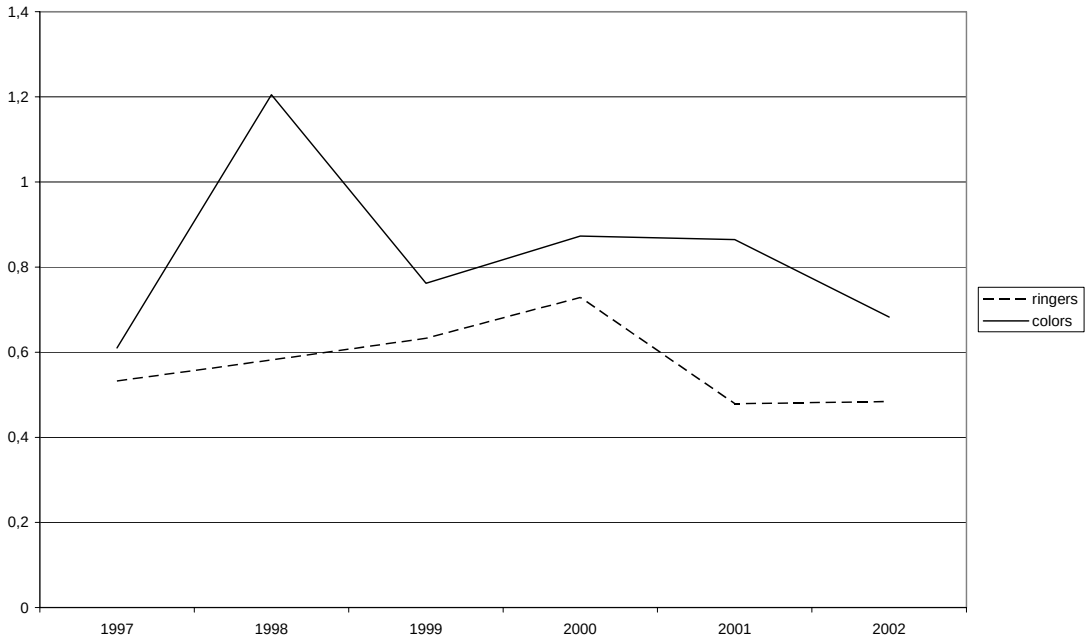


Figure 8 indicates that (at least) since 1997, there has been a relatively high degree of horizontal differentiation in terms of design or style features of cellular handsets. In 2002, design still remained one of the strong horizontally differentiating features of new handsets. One potential explanation for this is that design features are i) not necessary limited by technological boundaries, and ii) they don't involve a trade-off between cost, talk time and the feature in question. Along similar lines, talk time also did not converge further in later stages of the lifecycle (in fact the coefficient of variation even increased post-1995), as talk time was likely to decrease with the number of additional features offered with the phone, so that a tradeoff has to be made.

iv) Additional functions

We also have information on a set of additional features that do not relate directly to the management of voice or data communications but add value or functionality of a cellular phone. These features include the availability of a clock, alarm clock, games and calculator. There has been strong convergence in terms of these features (see Figure

9). In 1996, none of our sampled models comprised games or clocks, and alarm clocks and calculators were not common either. By 2002, games and clocks had become standard features - a dominant design in the category of additional mobile phone features - and most new mobile phone models also offered an alarm clock and a calculator.

Figure 9. The coefficient of variation for additional functions

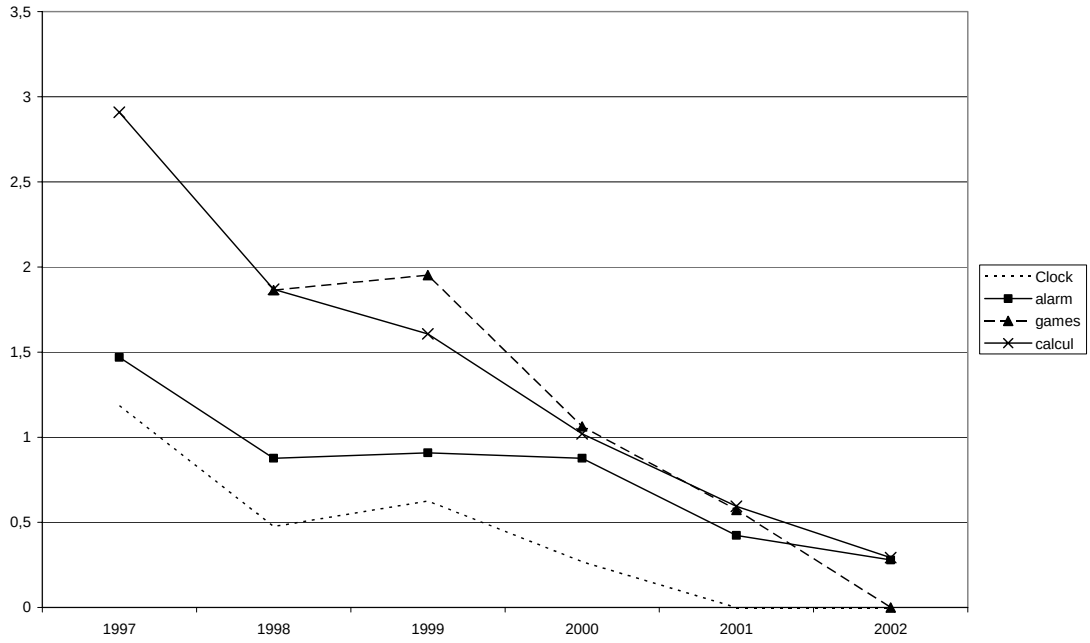


Figure 10 summarizes our main results concerning horizontal and vertical innovation patterns in global handset markets during 1992-2003. Certain horizontal innovations such as clocks, games, SMS, speed dialing and vibration alert have become so common in mobile handsets that they constitute a dominant design at the level of additional features. Various other features such as the number of ringtones and colours available, alarm clocks and calculators remain as horizontally differentiating features. In our sampled data we do not find a clear dominant design in vertical innovations though clearly handsets have become more homogenous in terms of their technical performance and weight. It seems likely that variation in handset design and dimensions is related to

the fact that mobile phones are also fashion items and arises largely from production for the segment of fashion phones. Technical improvements have enabled the production of lighter handsets but variation in handset size has not converged due to the emergence of new fashionable handset designs such as clamshell phones.

Figure 10. Horizontal and vertical innovation patterns in global handset markets, 1992-2003

Innovation type	Dominant design	Differentiation
Vertical innovation		Handset weight Talk time Standby time
Horizontal innovation	Speed dialing Vibration alert SMS Clock Games	PC synchronization WWW capability Number of ringtones Colours Alarm clock Calculator Handset size

4. Why does innovation come in phases: the role of consumer preferences and entry

The state of the technology life-cycle and demand affect innovation and may provide at least part of the explanation for the observed phenomena. Most models of technology diffusion assume that a technology does not develop over time apart from exogenous price decreases due to process innovation (see, e.g. Stoneman, 1999). Our conceptual framework offers a departure from this as we combine the incentives to innovate with the nature of demand. In the early stages of the market, technological advancement generally leads to a relatively large increase in consumers' marginal utility and thus demand. This gives firms incentives to invest in quality improvements in technology. At the same time, since these vertical innovations present a clear improvement over the status quo and market share shifts towards the manufacturers that offer the most advanced handset, rival firms will imitate such improvements, implying that the variation in these product dimensions will decrease continuously after a period of intense innovation.

In mature markets, when technological quality is already relatively high, users' marginal utilities from technological improvements are decreasing (Adner and Zemsky, forthcoming) and profits from vertical innovation shrink. Demand comes mainly from replacing existing handsets, and mass market consumers are also more heterogeneous than early adopters of mobile phones, which means there is more need to differentiate horizontally. When technological improvements are not very valuable to existing mobile phone users, the only way to generate new handset demand is through additional product features for existing users in order to overcome switching costs. Switching costs in this industry arise from learning effects and brand loyalty; users tend to buy mobile phones of the same manufacturer as switching to a competitor would require users to

invest in learning to use a new handset.[24] Successive generations of new handset models of each manufacturer then tend to follow a similar logic in their functioning (e.g., the location of the keys providing certain functions) reducing brand loyal users' learning costs to (close to) zero.

The second stage of innovation in the mobile handset industry can therefore be explained by the growing importance of replacement demand and the growing heterogeneity of consumers, which implies that firms focus on both vertical innovation (to induce switching) and horizontal innovation (to relax price competition) simultaneously. This pattern corresponds to the max-min principle outlined in Neven and Thisse (1990) or Vandenbosch and Weinberg (1995), where firms will want to cluster on one dimension (in our case, quality) and disperse in the other (in our case, horizontal differentiation). This pattern was only stable once there was sufficient heterogeneity on the part of consumers so that it was profitable to differentiate in the first place.

Innovation has been a stable feature on the market for mobile phone handsets. Table 2 gives the number of patent applications of the three largest manufacturers of mobile handsets over our study period. If patent applications are anything to go by, innovation has intensified in the last few years, despite the industry maturing.[25] Any attempts at explaining the pattern of innovation in this industry therefore has to allow for continuing R&D incentives by firms over the two stages of innovation.

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[24] The two largest manufacturers of mobile phones, Nokia and Motorola, are consistently ranked in the Top Ten for brand loyalty in the US (http://www.brandkeys.com/awards/leaders.cfm).

[25] Although this figure refers to the firms' patent applications for all their businesses, the proportion of patents referring to the mobile phone handset market appears to have been relatively stable according to the company websites.

Table 2: Patent Applications by the three largest handset manufacturers, 1991 - 2001.

	Number of US patent applications by 3 biggest manufacturers		
Year	Nokia	Ericsson	Motorola
91	25	40	640
92	45	52	690
93	56	67	798
94	91	103	967
95	110	110	1116
96	101	216	1168
97	113	195	1192
98	243	443	1556
99	340	684	1276
00	350	823	1274
01	402	792	820
02	503	776	749

Along with the intensity and character of innovation, the number of actively innovating firms in the industry also varied strongly. Early markets have relatively few firms, expansion in demand attracts more companies and creates the peak period of competition in product market, and finally fierce competition attracts less entry and also forces part of the companies to leave the market. The number of firms is generally related to more product variety and competition over the dominant design, whereas it is often said that new entrants contribute most of the innovations in an industry.[26] For instance, Czarnitzki and Kraft (2003) find in a sample of German manufacturing firms that challengers typically invest more in innovation.

Figure 11 shows that there have actually been two peaks in the number of innovating entrants during the years 1992-2003. The first entry peak around the mid 1990s relates to the substantial improvements in technical quality and capability of mobile handsets that happened, by and large, due to the digitalization of handsets (i.e. market entry of 2G phones). Market entry peaks at the same time as variation of handset weight is highest, while the variation of talk and standby times reaches its highest level two years

[26] Both theoretical literature on entrepreneurial innovation beginning from Reinganum (1983) and empirical studies (e.g. Czarnitzki and Kraft, 2004) suggest that the market entrants tend to be more innovative than the incumbents firms.

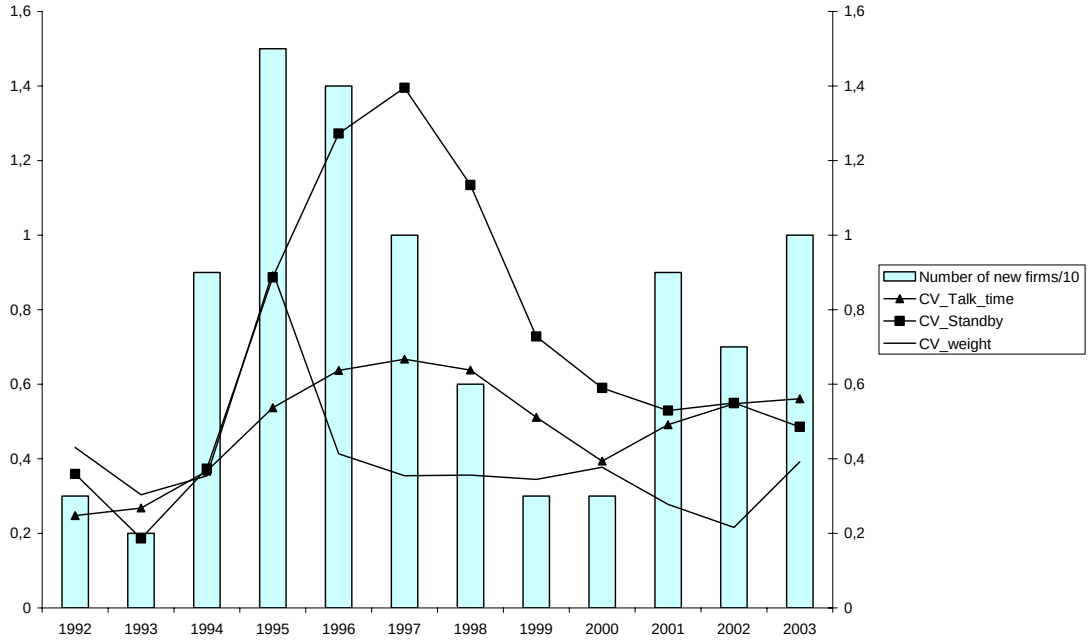
later. We then observe less entry until 2001-2003 when the number of new firms in the market picks up again. Our figures of the coefficient of variation of various vertically and horizontally differentiated features don't seem to react to this entry notably.

The market entry of 3G phones might explain the growth in the number of entrants during the years 2001-2003. The next generation mobile handsets created market opportunities for new players with innovative ideas and possibly capabilities different from those of the incumbents. Our data also show that many new entrants were expanding their business from other ICT manufacturing sectors such as PC production (e.g. Arima) - probably for decreasing profit margins for personal computers. The chairman of the Zhongxing Telecommunication Equipment Co. Ltd. (ZTE), a Chinese telecom giant, told that there were two reasons for ZTE entering the mobile phone market: "*First, there´s great potential in the mobile phone market. Second, ZTE has an extensive technology base relevant to GSM, CDMA and PHS, as well as a thorough knowledge of telecommunications*."[27]

It seems that in the market for mobile handsets, market entry and variation in new products has been greatest the years right after the introduction of products using new system level innovation, i.e. 2G and 3G handsets. Our data suggest that product innovation and market dynamics evolve dynamically, and some peaks in these two dimensions coincide in their timing and length, but they are not inextricably linked to each other.

[27] Source: Hou Weigui: Keeper of ZTE´s Vitality, *Shenzhen Daily* 2005-05-17. http://www.zte.com.cn/English/02news/TE

Figure 11. New handset manufacturers with product innovation (scaled dividing by 10) and coefficient of variations for vertical innovation measures



The role of entrants as the primary source of product innovation does not seem to be confirmed in mobile phone markets if we measure innovation merely by the number of new products. Almost 40 % of new handset models launched between 1992 and 2003 were produced by the five biggest cellular phone manufacturers. However, while incumbents account for a notable share of new handsets, the number of new firms is related to the degree of technological variation; the positive correlation between the number of entrants and technological variety of new handset models measured by the average coefficients of variation of weight, talk time and standby times is quite high (.75) over the years 1991-2003. Conversely, the number of all firms launching new handsets was correlated more weakly with the degree of technological variety (.44). This is consistent with the view that the path towards dominant design involves a phase attracting new firms with competing designs to the market (Christensen, Suarez, and Utterback, 1998).

5. Conclusions

Technological development, handset design and product market competition are tightly linked to one another. We summarize the corresponding eras of competition related to the major trends or cycles in handset design as follows:

1) The era of weight and size competition (from the early 1980s until about 2000) - vertical product homogenization.
2) The era of (increasing) customer segmentation and product differentiation (From late 1990s onwards) - horizontal product differentiation with continued vertical innovation to spur replacement demand.[28]

By the end of the 1990s, competition combined with technological development had led to vertically relatively homogenized mobile handset production but no dominant design emerged. Instead, various - but not all - vertical innovations such as SMS and games were adopted in all new handset models and thus formed a dominant design at the level of handset features. Other vertical innovations such as calculators, alarm clocks and some design features (variation in colours) remained as vertically differentiating characteristics of mobile handsets The dominant design handset model in the beginning of 2003 was a compact communications device that included at least SMS, speed dialing and vibration alert options, clock and games.

Our data also show that the relationship between product innovation and market dynamics relates to the timing and strength of the phases of product innovation. In mobile handset markets, the greatest rate of market entry followed system level innovation and competition took place in horizontal and vertical innovation dimensions.

[28] Nokia was the leader in realizing that the general laws of consumer marketing such as customer segmentation apply to the mobile sector. According to Steinbock (2003), Nokia's superior handset design was not the only determinant of its market success but its strategy to focus on segmentation (to dominate categories) and continuously launch new models (every 35 days by late 1998) was raising Nokia to the cellular handset production and sales front.

When the peak development of core technological quality of 2G handsets and related market entry was over, market entry slowed down until the new market prospects emerged along with the introduction of the first 3G phones.

New 2G handset models are still being launched but during the coming years many users will replace their old 2G handsets with new 3G ones. Competitive strategies of mobile phone manufacturers as well as advancements in wireless technologies will determine the development of future mobile handset mix.

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Appendix 1. Description of the data

The data comprise 2466 new handset models launched during the years 1992-2002. The data on manufacturer, technology, size (i.e. height, width and thickness), weight, talk times and standby times are compiled from EMC World Cellular Database.

The data concerning the additional functions (i.e. clock, alarm, games and calculator), design features (i.e. colours and ringer tones) and voice and data communications features (vibration alert, number of memory locations, speed dialling option, www capability, SMS function and PC synchronization) of new handset models were compiled from 3 different web pages:

1) http://www.cellphones.ca

2) http://www.cellular-news.com/cell-phones/

3) http://www.gsmarena.com/index.php3?sRedir=http://www.gsmarena.com/phone11.php.

The data on additional features is limited to the models launched during the years 1995-2002. These data do not cover new handset models that use the Japanese PHS/PDC standard.

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