The Product Life Cycle Theory and Product Line Management: The Case of Mobile Phones

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The Product Life Cycle Theory and Product Line Management: The Case of Mobile Phones

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Abstract—**This paper applies the product life cycle theory to the issue of product line management with two goals in mind: 1) to understand how product line management evolves over the life of an industry and 2) to compare Klepper's model (1986), which emphasizes economies of scale, with the traditional model of the product life cycle, which emphasizes dominant designs. We find that Klepper's model of the product life cycle theory in combination with the concept of product line management provides a better explanation for the evolution of competition in the mobile phone industry than the traditional product life cycle model. We use Uzumeri and Sanderson's classifications of product variety and change (Uzumeri, 1995) to generalize from the industry case.**

Index Terms—**Cellular, designs, development, dominant, Ericsson, lifecycle, mobile, motorola, nokia, product.**

I. Introduction

THE PRODUCT life cycle is an important theory in the fields of management and economics. Technological discontinuities cause a period of ferment in which alternative product forms compete for dominance due to the large amount of market and technological uncertainty that exist following a technological discontinuity. New firms enter the market and competition focuses on product innovation. Eventually, however, the process of experimentation between the firm and the users of the product leads to the appearance of a dominant design where standardized parts, software, and manufacturing equipment appear [2], [3], [28]. The appearance of this dominant design causes the competition to change from product or service performance to the effective use of complementary assets such as marketing, distribution, competitive manufacturing (e.g., process innovation), and after-sales support [27]. Firms who are unable to successful produce the dominant design or do not have the required level of capabilities in the complementary assets often exit the industry [4], [29].

The most controversial aspect of the product life cycle theory is the role of dominant designs. Research suggests that the concept does not apply to some products and systems [13], [22] and a single dominant design has not emerged in many industries [9], [32]. The strongest criticism of this concept comes from Klepper [16]. His model of the product life cycle uses economies of scale and convex adjustment costs, as opposed to dominant designs, to explain reported patterns of firm entry and exit and increased spending on process innovation. In turn, reduced firm entry and firm asymmetries in capabilities lead to a reduced spending on product innovation.

This paper applies the product life cycle theory to the issue of product line management with two goals in mind: 1) to understand how product line management evolves over the life of an industry and 2) to compare Klepper's model with the traditional model of the product life cycle. To our knowledge, this will be the first paper to address the first question and, thus, provides a starting point for research in this area. Although there is a large volume of literature on related topics like multiproject management and the use of common platforms,[1] these analyses do not address the evolution of product line management over the product life cycle and instead largely analyze mature products.

This paper uses the mobile phone industry to look at these two questions.[2] Using Uzumeri and Sanderson's [30] classification of product variety and change, there is both a large variety of and fast rate of change in both families and models and, thus, the mobile phone industry occupies the upper right corner of each quadrant (see Fig. 1).[3] Mobile phone firms typically define product families in terms of different analog and digital air-interface standards; these standards define the interface between the phone and the base station. Within a specific standard, different models are developed for different users and user needs. When there are many models and/or families and change is slow, traditional methods of platform management that emphasize the use of common parts are relevant (e.g., see [19]). When there are few models and/or families and change is rapid, innovation and fast product development management are important (e.g., see [26]). When there are both many models and change is rapid, both common parts and innovation become important and the mobile phone industry provides insight into this pattern of platform management.

This paper also uses Wheelwright and Clark's [31] classification of development projects. Development projects can be classified as breakthrough, platform and derivative projects. Breakthrough projects involve significant change in the product's core concepts (e.g., new families), platform projects create new system solutions (sometimes called platform products[4]), and derivative projects involve incremental change.

We find that Klepper's model of the product life cycle theory in combination with product line management provides a better

[1]Examples of the former include [7] and the latter include [19] and [28].

[2]Reference [10] describes this case and other aspects of the mobile phone industry in more detail.

[3]The author is indebted to one reviewer for the reference to Uzumeri and Sanderson's paper.

[4]We are using the concept of platforms that is described by [19] as opposed to a more recent and broader concept that has been introduced in [12].

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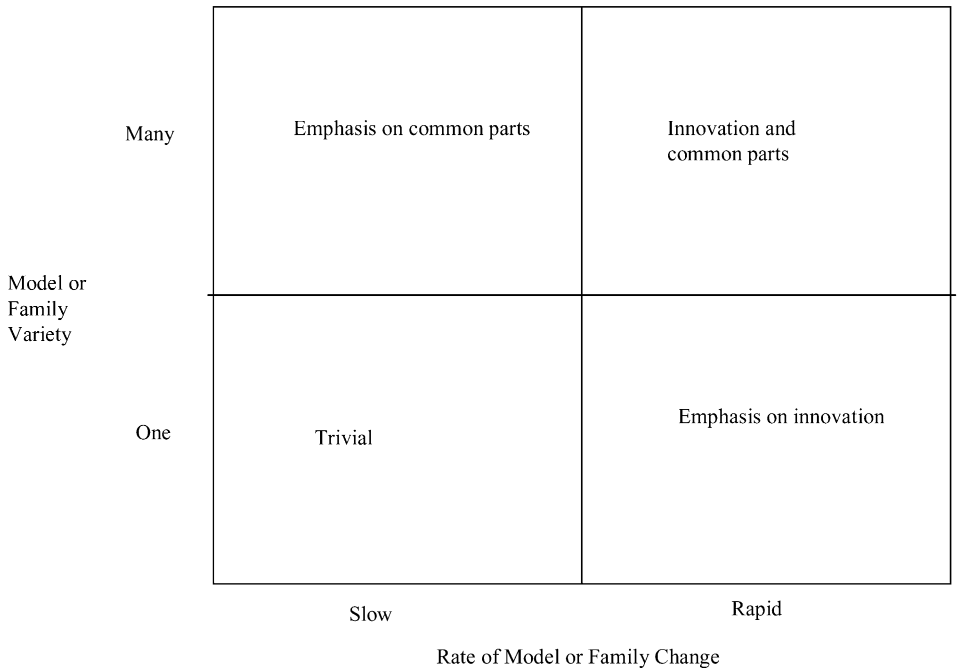

Fig. 1. Platform management and patterns of model and family evolution.[5]

explanation for the evolution of competition in the mobile phone industry than the traditional product life cycle, provided two caveats are introduced. First, the role and effect of economies of scale are a function of firm strategy. The market that constitutes the economies of scale depends on the degree to which a platform covers multiple families (e.g., standards) and models, which is one aspect of product line management. The effect from economies of scale also depends on firm pricing strategies, which has been documented in historical analyses [6], [14] and extreme discounting in order to benefit from these economies of scale became the cornerstone of some strategies such as those recommended by the Boston Consulting Group [5]. Many argue that this strategy was taken to unprofitable extremes in the 1970s [1], [8], [20], [21].

Second, depending on the firm's strategy with respect to product platforms, it is largely market growth in a particular standard that defines the economies of scale. In this way standards do act as dominant designs in that they require firms to develop capabilities in the standard. However, the selection of these standards in committees (i.e., dejure standard) eliminated the predominant design phase of competition in the mobile phone industry or at least relegated it to competition within a committee [25].[6]

Following a summary of the research methodology, this paper chronologically summarizes product line management and competition in the mobile phone industry. It breaks this history into: 1) analog (1981–1995); 2) Global System for Mobile Communication (GSM) (1992–1998); 3) global digital (1996–1999). Global market shares are shown in Table I and share rankings for different mobile phone markets are summarized in Table II.

[5]The patterns of model evolution are adapted from [30].

[6]It can be argued than the global standards that have emerged from competition between various regional standards can be deined as defacto standards.

TABLE I
GLOBAL PHONE SHARES

Firm	1997	1998	1999	2000	2001 (1Q)	2002 (1H)
Nokia	20	22.5	26.9	30.6	35.3	36.3
Motorola	25	19.5	14.6	16.9	13.2	16.4
Samsung		2.7	4.6	5.0	6.3	10.1
Siemens	3.6	2.9	6.2	6.5	6.9	8.7
Ericsson	16	15.1	10.0	10.5	6.8	5.8
Panasonic	7.3	8.2	5.5	5.2	4.7	
NEC	5.0	4.2			3.4	
Mitsubishi	3.0	2.8	3.4		3.0	
Lucky Goldstar					2.8	
Alcatel	2.5	4.3	4.2		2.6	

Source: Gartner Dataquest except for 2002 (strategy analytics).

TABLE II
MOBILE PHONE MARKET SHARE RANKINGS BY FIRM AND STANDARD

Firm	Standard							
	Analog				Digital			
	US AMPS		NMT	TACS	GSM	TDMA	PDC	cdmaOne
	1989	1996	(1991)	(1994)	(1998)	(1998) (US)	(1999) (Japan)	(1998) (US)
Nokia	10	2	2	2	1	1		2
Motorola	1	1	1	1	2			3
Ericsson	9	8	3	3	3	2		
Matsushita	2	6	5		7		1	
Sony/ Qualcomm								1
NEC					9		3	
Siemens					5			
Alcatel					4			
Mitsubishi	3	5					2	
Philips			4		6			
Toshiba	4	9					6	

Source: [10].

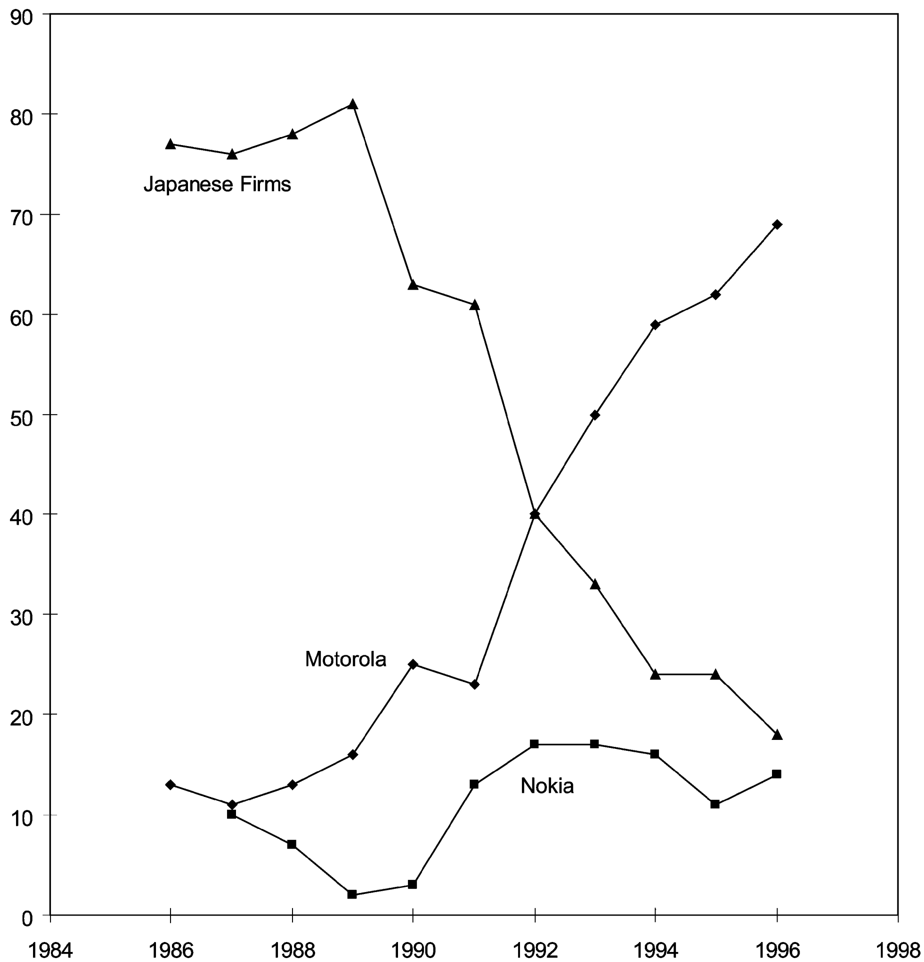

Fig. 2. Shares of U.S. analog mobile phone market.

II. Research Methodology

The research methodology consists of both published information and interviews. Published information was found in U.S. and European newspapers, industry journals, and consulting reports. More than 35 interviews were also conducted with product development and marketing managers in 11 U.S., European, and Japanese firms including multiple interviews in Motorola (5), Ericsson (8), and Nokia (10) between 1996 and 1999.

III. Analog Market (1981–1994)

Many countries started analog services in the first half of the 1980s that were based on different standards of which the most successful were based on the Nordic Mobile Telephone (NMT) system and Advanced Mobile Phone System (AMPS); phones for these different standards can be defined as different families. Scandinavian and other firms developed the NMT system and by the end of 1982 four Scandinavian and two other countries had implemented services that were based on the standard. U.S., Canadian, and other firms created the AMPS standard and services were started in 1983. By the end of 1985, six countries had started services that were based on the AMPS standard or its derivative, theoretical aspects of computer software (TACS) [11].

These markets experienced a large number of manufacturing entrants particularly in the U.S. market where a large number of Japanese firms entered the market. Within a year of the start of services more than ten manufacturers had released phones. As shown in Fig. 2,[7] Motorola and the Japanese firms were the leaders as they were expected due to their experience in the private mobile radio and consumer electronics industries. Following brief leadership from Oki Electric and Toshiba, Motorola became the leader in 1988 with a 13.2% share followed by Matsushita, Mitsubishi, Uniden (all with shares over 10%), Toshiba, NEC, Oki Electric, and Shintom, and JRC. Between 1986 and 1989, Japanese firms had between 77% and 81% of the top ten U.S. markets for nonportable phones (car and transportable phones) [24].

A. Acceleration in Market Growth

Growth in the market began to accelerate in the late 1980s through the interactions between falling prices and a growing market, the variables that are the heart of Klepper's model [16]. Both the wholesale and retail prices of phones were dropping dramatically due to technological progress in the semiconductor industry and rising activation commissions from the service providers also drove down the retail prices. Service providers began signing up large stores such as Sears, Macy

[7] Source: [21].

& Company, and Tops Appliance as exclusive distributors and paying them to sign up subscribers. In early 1990, the activation commissions were about $300, thus making it possible to obtain in some cases a phone and contract for less than $70.[8] The phone prices continued to drop such that by 1994, the average retail phone prices were $300 for mobile phones and $568 for portable phones. These lower prices caused the phone market to rise from 1.5 million phones to 6.0 million phones a year between 1989 and 1994 [24].

Motorola was the first firm to notice the acceleration in growth and implement a new strategy not only in the AMPS but also in the TACS (Great Britain was the biggest user) and NMT (Scandinavian) markets. Motorola began giving volume discounts to service providers and extracting volume discounts from suppliers. It set low prices on the expectation of receiving these volume discounts and it used the increasing volumes to rapidly reduce its costs. Naturally, the similarities between the AMPS and TACS standards allowed large economies of scale between the two standards.

Motorola also expanded its number of models including the selling of its new and old phones simultaneously in different price segments; this is consistent with a "dynamic" pattern of model evolution [30]. In some cases the older phones were slightly modified for the lower-end of the market using cheaper integrated circuits and discrete components. This strategy enabled Motorola to better meet a wider variety of consumer needs while the costs were kept down through the large number of common parts. Further, it set particularly low prices for the low-end phones where it did not expect to make money. Instead, it made its profits on the high-end phones.

By 1992, Motorola had 40% of the U.S. market or about four times the share of its closest Japanese rival, Mitsubishi [24]. This provided Motorola with strong advantages of scale in production, procurement, and distribution. Procurement was critical since semiconductors and discrete components, which are very volume sensitive parts, made up a large percentage of product costs. The disadvantages of the Japanese firms were also exacerbated by their emphasis on the use of internal parts. Most of them either exited the analog market or they chose not to develop nest-generation digital phones.

It should be noted that a dominant design did not appear during this time period. Instead, improvements in electronics caused phone prices, weights, and sizes to gradually decline, a trend that still continues.[9] While some people might argue that the emergence of a portable phone represent a dominant design, it was not until 1994 that portable phones represented 50% of the U.S. market and this was long after the abrupt falloff in the shares of Japanese firms.

B. Other Markets and Other Firms

Motorola also created a volume advantage in the Scandinavian NMT market although acquisitions played a more important role in this market than in the AMPS market. Motorolas share began to increase in 1988 due to its acquisition of three Scandinavian manufacturers, Storno, Esselte, and Talkline in the mid-1980s and the substantial volume discounts that it began to offer to carriers in 1988. This caused the price of its phones to drop by 30%. Ericsson was forced to lose money in order to maintain its market share [18]. By early 1991, Motorola had achieved the top share of 26% when the shares from its acquisitions are included. Nokia Mobira (it acquired Mobira in the early 1980s) was second with 24.4% (including Technophones 5.6%), followed by Ericsson with 20.1% (including the 6% from its joint venture with Panasonic), Philips (9.9%), and Mitsubishi (5.6%).[10]

Nokia and Ericsson were also early entrants to the U.S. market although Nokia moved faster to copy Motorola's strategy and emphasize volume discounts and inexpensive phones; one aspect of its strategy was a close relationship with the consumer electronics store, Tandy. But Nokia's most important decision was the acquisition of the British firm Technophone in February 1991. The successful acquisition of Technophone caused Nokia to instantly become the third-largest provider of phones in the U.S. and the second-largest provider in Europe. The acquisition of Technophone enabled Nokia to create greater economies of scale both in production and procurement for AMPS- and TACS-based phones. Further, in a move that would eventually enable it to become the leading producer of phones in the world, it began creating global platforms that could be used to develop phones for multiple standards.

IV. GSM (1994–1998)

European firms created the digital GSM standard in the late 1980s and early 1990s and phones were available in 1992[11] [11]. The much faster growth in the GSM than AMPS market caused the phone market to quickly pass through the medium-volume production that characterized competition in the early part of the analog market. Instead, phone costs dropped quickly and the leaders quickly introduced volume discounts and received them from parts suppliers. While it took almost five and 11 years for the number of annual AMPS phone sales to pass the 1-million and 10-million marks, respectively, it took less than 1-1/2 and 3-1/2 years, respectively, for the number of GSM phone sales to pass these marks [11].

Motorola, Nokia, and Ericsson invested heavily in the development and production of phones and pushed these volume discounts due to their optimistic predictions about the market. Their optimistic predictions about the market reflected their success in the NMT and AMPS markets. Other European firms like Dancall, Hagenuk, Ascom, Bosch, and even to a some extent larger firms like Siemens, Alcatel, and Philips were from countries where analog phone and even to some extent wireline-phone competition was based on exclusive relationships between manufacturers and service providers. These firms were ill prepared for regional much less global competition and their narrow perceptions of the market prevented them from making

[8]For example, see "Cellular Marketing Sees an Edge Through Special Offers and Spying," Wall Street, May 15, 1990, p. bl.

[9]It can be argued that mobile phones have reached their minimum size due to physical reasons (e.g., the distance from the mouth to the ear and the size of fingers) and a change from a voice to data-based device (which is causing screens to become larger).

[10]In 1991, Storno had 9.3%, Esselte had 3.8%, and Talkline had 1.5% [15].

[11]Because the phones utilized a new core concept, digital technology, we can define the first development projects as breakthrough projects.

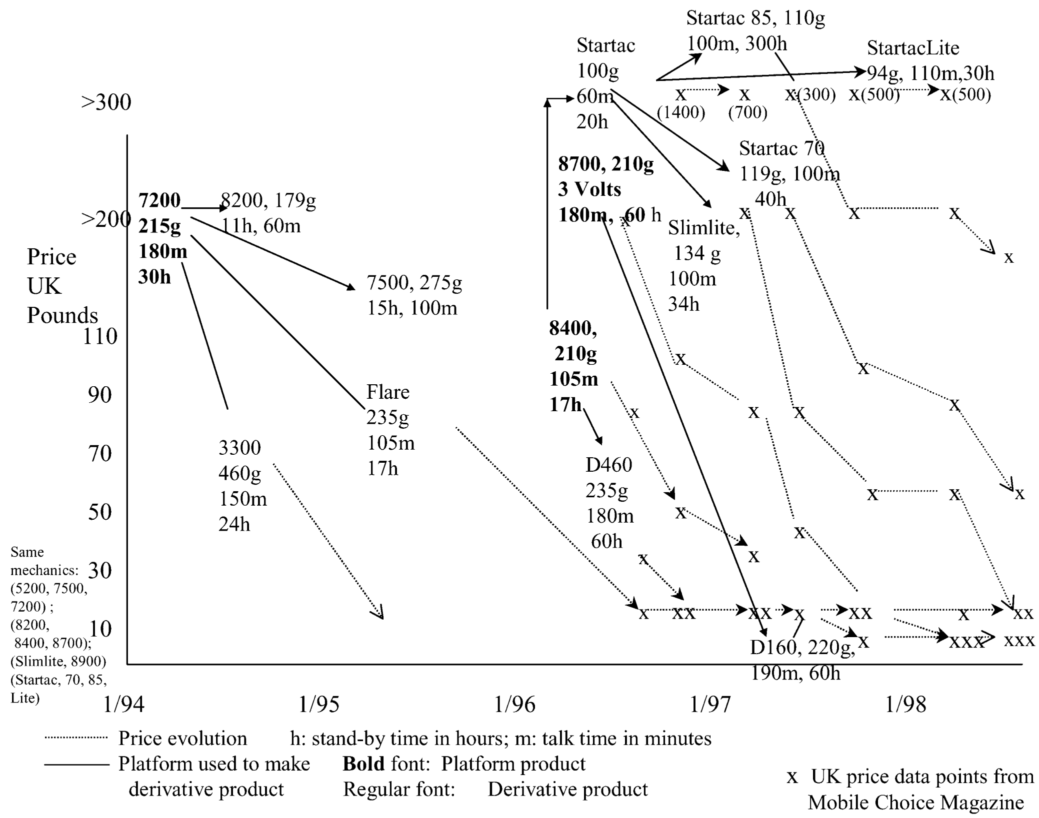

Fig. 3. Evolution of Motorola's GSM 900 MHz phone line.

the necessary investments in technology, products, and manufacturing capacity. Except for Siemens and Alcatel, all of the above-mentioned firms had quit the market or been acquired by larger rivals by the year 2001 and most of them much sooner.

Japanese firms were also slow to enter the GSM market but for a different set of reasons. The European committees associated with the GSM standard required firms to have a European development center in order to participate in the development of the GSM standard. While Motorola created such a development center in Great Britain, Japanese firms did not. This prevented them from simultaneously developing products, while participating in the standard setting process and, thus, they did not have any patents to exchange with Motorola and the European manufacturers. They were forced to pay licensing fees of between 6% and 10% as a percent of sales. These patent negotiations caused Mitsubishi, Matsushita, and other Japanese firms to substantially delay their entry into the GSM market.[12]

A. Product Line Management and Entry Barriers

Beginning in 1994, Nokia and to a lesser extent Motorola and Ericsson also implemented a product line management strategy that increased the entry barriers for other firms beyond their already existing advantages in economies of scale. In their expansion of the number of models, which is consistent with a "dynamic" pattern of model evolution (Uzumeri and Sanderson, 1995), they used a large number of common parts in multiple segments and subsidized their low-end phones (see Figs. 3–5). Most firms admitted that they either lost money or barely break even in the low-end of the market while the high-end of the market is where Nokia and to some extent Motorola and Ericsson make their profits.

These three firms quickly created a strong brand image in the high-end of the market and, thus, have been able to differentiate themselves from the other manufacturers in this market. The low-end phones from Motorola, Nokia, and Ericsson merely provide the volumes necessary to have low costs in both the low-end and high-end phones, again consistent with Klepper's model [16], and reduce the amount of price erosion in the high-end phones. Further, the brand images they created in the high-end segments were to some extent subsequently carried over into the low-end segment and these high brand images enable them to charge slightly higher prices than the other manufacturers in the low-end segment.

This strategy made it difficult for firms to gradually move from the low-end of the market to the high-end of the market as the Japanese did in a variety of industries such as automobiles and consumer electronics during the 1970s. Without profitable products in the low-end of the market, it is often difficult to justify entry into the high-end of the market. This is the major reason why Sony quit its joint venture with Siemens in the GSM market where neither Siemens itself or both together were able to crack the entry barrier created by Nokia, Motorola, and Ericsson.[13] Philips tried to crack the barrier by copying

[12]See Nikkei Industrial, September 13, 1994, "Dejitaru keitai denwa nihonzei ohshu sanyu ni deokure—tokkyo ru-ru ni bei motorohra nado hanpatsu, Japanese digital phone manufacturers had a late start in the European market—U.S. Motorola and others enforce patents."

[13]See Nikkei Journal, November 12, "Sony Ohshu muke keitai denwa kohkinh jisha kaihatsuki shuryoku ni—kakaku kyosoh, Sony develops high functional mobile phone for the European market to avoid price competition."

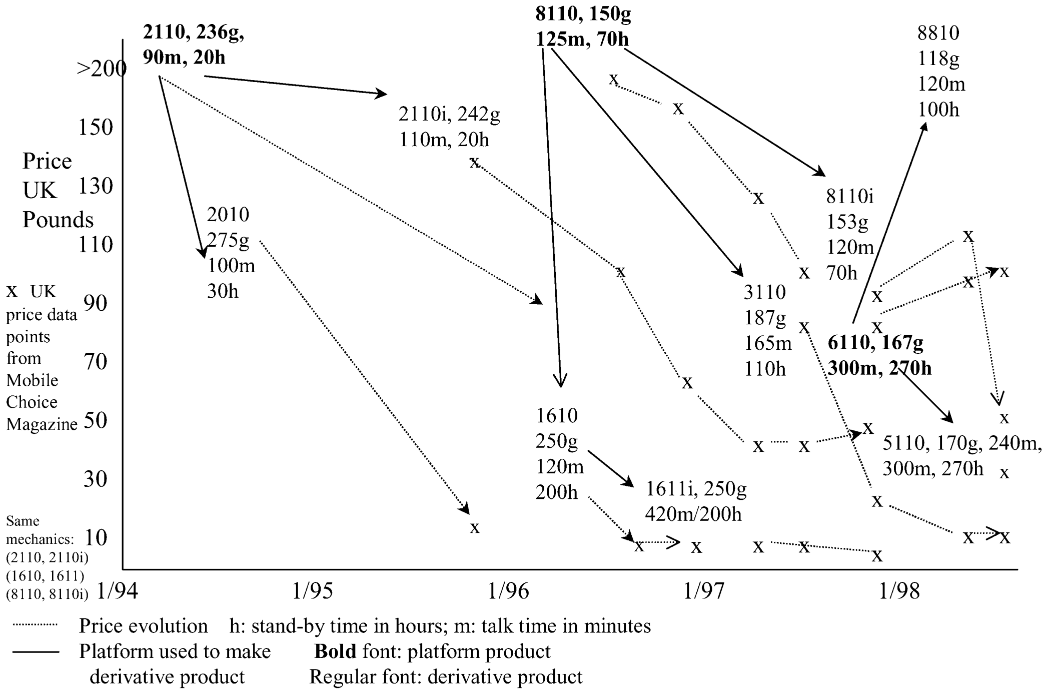

Fig. 4. Evolution of Nokia's GSM 900 MHz phone line.

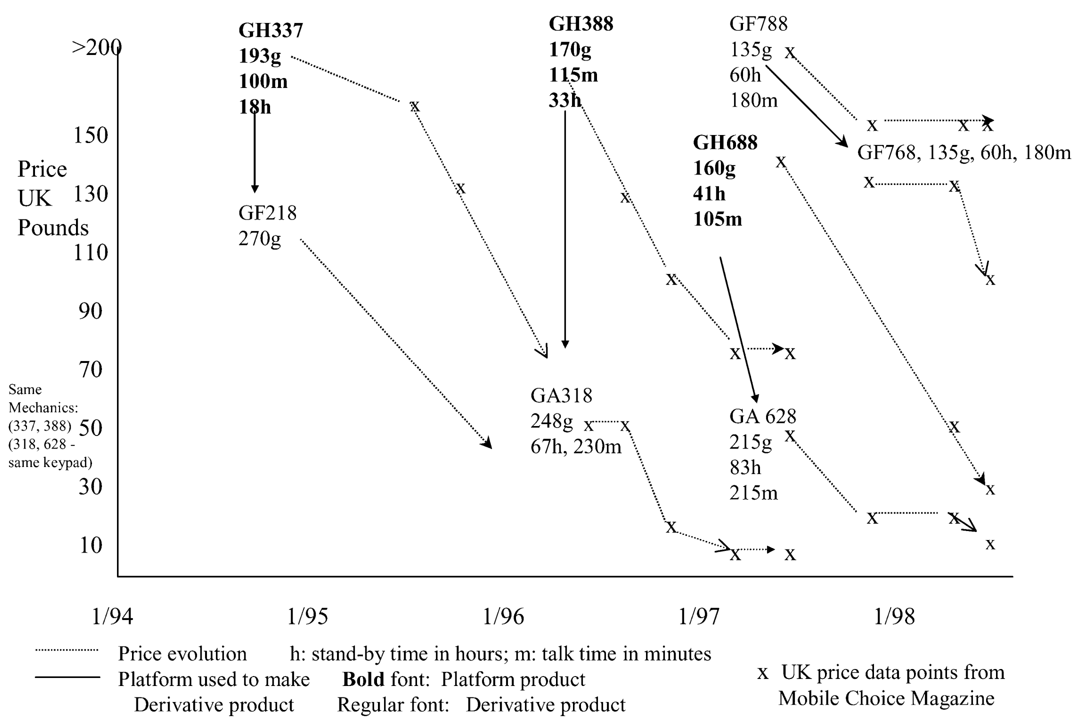

Fig. 5. Evolution of Ericsson's GSM 900 MHz phone line.

their strategy and introducing phones in each segment of the market in 1996 but exited the market in 2001.

B. *Differences in Product Line Management*

Differences in product line and platform management also partly explain the greater success of Nokia and Ericsson's abrupt loss of share beginning in 1999. These differences include strategic differences like the ratio of derivative to platform products and method of differentiation and implementation problems for Motorola and Ericsson. As shown in Table III, Nokia and Motorola introduced far more products than Ericsson between 1994 and early 1998 because they introduced derivative products both simultaneously and subsequently to the introduction of a platform product, while Ericsson only did the former. This enabled Motorola and Nokia to more effectively cover the various price segments in the market while maintaining lower development cost/product than Ericsson.

TABLE III
GSM 900 PLATFORM MANAGEMENT STRATEGIES BETWEEN 1994 AND 1997

Item	Nokia	Motorola	Ericsson
Number of Platform Products	3	3	3
Number of Derivative Products	8	10	5
Ratio of Derivative to Platform Products	2.7	3.3	1.7
Total Development Costs (1)	4.29	4.80	3.50
Development Costs/Product	.39	.36	.44

(1) Units are in "standard development projects," where a standard development project includes a phone with a new architectute, baseband chips, discrete components, printed circuit board(s), mechanics, and software.
Source: [10].

The second strategic difference involves the method of product differentiation. Motorola has primarily emphasized the development of very-light phones for the high-end of the GSM market, Ericsson has emphasized low cost, and Nokia has emphasized aesthetic design, user interface, and software features. The Startac played this role in the U.S. market and Motorola developed similar versions for the GSM market. Ericsson's emphasis on product cost is why it only introduced derivative products simultaneous with the introduction of a platform product. This was part of Ericsson's strategy to cost minimize each platform design from the beginning, whereas Nokia often reduces the cost in the subsequent derivative products.

Nokia has placed more emphasis on aesthetic design, user interfaces, and software features than on weight or costs and these three factors have become much more important than they were in the analog era. Designs with rounded edges, good proportions, interesting colors, and high-quality mechanical components such as higher resolution and sometimes larger displays, hardtop as opposed to rubber keys, and magnesium as opposed to plastic housings have become key features in the high-end phones. Further, the increasing importance of message and data services, memory dialing, answering services, caller notification, vibration notification, and the control of everything from display strength, button and ringing volume, ring tone and melody, clock and alarm, to security features has increased the importance of both user interfaces and software features.

C. Implementation Problems

Motorola's and Ericsson's implementation problems with respect to platform management caused Motorola's share to drop in 1996 and 1997 and Ericsson's to drop in 1998 and 1999. First, Motorola's three platform projects were not evenly spaced between 1994 and 1998 and, thus, technology was not used as effectively as it could have. Second, Motorola allowed a large gap to appear in the mid-price segment of the 900-phone market, which Nokia was able to dominate with its 3110, 8110i, 6110, and 5110 phones between 1996 and 1998. The reason is that Motorola thought that the 1800 market was ready to take off in 1998 and, thus, was the first firm to introduce a dual-mode phone (for the 900 and 1800 markets), called the 8900, which was also a platform product for Motorola (see Fig. 3).

The lack of a new 900 MHz phone for Motorola in the mid-price segment caused Motorola to dramatically drop the prices of its higher end phones in 1997 and early 1998 in order to fill the vacant price segment (see Fig. 3). This strategy of aggressive price reductions that Motorola had successfully used in the AMPS market was much less successful in the GSM market due to not only changes in the customer needs but also the cost and weight drivers in mobile phones. Whereas in the analog market, semiconductor chips and discrete components drove weight and costs, mechanical components such as plastic housings, liquid crystal displays, printed circuit boards, keypads, shields, and antennas had gradually become a larger percentage of total phone weight and cost by 1998, and as they have become a larger percent of phone weight, it has become more important to use the most expensive mechanical components in the high-end phones in order to reduce the weight and improve the styling of the phones. These components include higher resolution and sometimes larger displays, hardtop as opposed to rubber keys, magnesium as opposed to plastic housings, and the latest printed circuit board technology. However, mechanical components are not as volume sensitive as semiconductor chips and discrete components are. Thus, the high-end phones need to be redesigned using less expensive mechanical components before they are sold in the lower price segments.

Ericsson suffered from much larger problems than Motorola did when it tried to change its method of product line and platform management. This included an attempt to introduce more derivative projects, an attempt to integrate Orbitel's development efforts with its own, and most importantly its attempt to redefine the market segments. Although Ericsson acquired Orbitel in 1991 (the same year Nokia acquired Technophone), it did not integrate Orbitel's product portfolio with its own until 1998.

Even bigger problems came from Ericsson's attempt to redefine the mobile phone market segments. Previously, it had defined the market segments (i.e., price) primarily by weight and to some extent design/user interface. The former was primarily Motorola's strategy with Nokia emphasizing the latter beginning in 1994 with the 2110. In 1998, Ericsson began trying to define the market in terms of entry level, design intensive, and functional phones. The design intensive phones were supposed to emphasize weight and size, while the functional phones were supposed to emphasize large displays and data capabilities. While this new definition of the market segments might have been more appropriate than the previous definitions, implementation problems prevented Ericsson from releasing any new phones between the end of 1997 and early 1999, thus causing its share of the GSM market and its corporate share price to drop dramatically.

V. U.S. AND GLOBAL DIGITAL (1996–1999)

The change from analog (AMPS) to digital standards in the U.S. market challenged Motorola's supremacy in the U.S. market. Digital phones required new capabilities in digital design and more importantly used different parts, thus eliminating many of Motorola's volume advantages in procurement that had come from its 70% share of the analog market. This enabled a number of firms to compete more effectively with Motorola, an argument that is consistent with Klepper's product life cycle model. The key difference with Klepper's model [16] is that new standards eliminated Motorola's volume advantages and some might call these standards a new dominant design.

A. Motorola's Mistakes

Several of Motorola's decisions placed it at a further disadvantage of which two are summarized here. First, Motorola initially chose to support only two (GSM and cdmaOne) of the digital standards adopted by U.S. service providers. The U.S. began awarding new licenses for digital services in 1995 and by 1996 many of these service providers had started their digital services. Although more than 50% of these new licenses were awarded to firms who elected to use cdmaOne [11], cdmaOne services took longer to implement and, thus, most of the early digital services were based on time-division multiple access (TDMA) and GSM. Motorola's lack of phones for the TDMA standard, which represented about two-thirds of the market for digital phones in 1996 and about 50% in 1997, caused its share of digital phones to plummet in these years.

Second, Motorola chose not to release a cdmaOne phone with its own chip set until volumes justified the development of such a chipset. The problem with this decision was that Qualcomm, the key patent holder in the cdmaOne standard, had decided to enter the cdmaOne phone market with Sony (they formed Qualcomm Personal Electronics) and, thus, Motorola and other phone manufacturers were depending on a competitor for the most important component in the phone. Further, the initially high licensing fees and fairly slow growth in the cdmaOne market also discouraged the large chip-set suppliers like VLSI Technologies (since acquired by Philips), LSI Logic, and DSPC Communications (since acquired by Intel), and even other Motorola competitors like Nokia from developing cdmaOne chip sets. Qualcomm was still the only supplier of chip-sets until the major chip-set suppliers such as VLSI began shipping samples in June 1998 and large volumes in early 1999.[14]

The big winner in the cdmaOne market has been Samsung. Although Sony and Qualcomm's venture Qualcomm Personal Electronics initially dominated the market, a number of quality problems emerged that reflected poor capabilities in volume production. Sony exited the market in 1999 and Qualcomm did so in 2000. Samsung was able to enter the U.S. cdmaOne market relatively early (in 1997) since the Korean firms had struck a special deal with Qualcomm in return for Korea's wholesale adoption of cdmaOne. Samsung also benefited from Korea's weak currency and the high growth in their cdmaOne domestic market where it was the number one supplier. The U.S. market for cdmaOne phones did not become larger than the Korean market until mid-1999 and these volumes have helped Samsung acquire a growing part of the U.S. market in 1997, 1998, and 1999, again consistent with Klepper's model [16].

B. Nokia's Global Development Capability

At the global level, the big winner has been Nokia through its development of a global development capability, which is an aspect of product line management. Nokia began developing global platforms in the analog era when it simultaneously introduced phones based on the AMPS, TACS, and NMT standards. Motorola also did this to some extent in the late 1980s and early 1990s when it used technology that was initially developed for AMPS phones in the TACS and GSM phones. However, while Nokia has continued to move toward a more integrated development process, Motorola gradually moved toward a regional organization where phone development decisions became very regionally independent.

As shown in Fig. 6, Nokia has used its three main GSM 900 platforms (2110, 8110, and 6110) to develop phones for the GSM 1800 MHz and 1900 MHz, TDMA 800 MHz and 1900 MHz, and to some extent personal digital cellular (PDC) 800 MHz markets. GSM 900 and 1800 are used primarily in Europe and Asia, while the 1900 MHz band is used for GSM in the U.S. and South America. The U.S. is the main market for TDMA 800 and 1900 MHz phones, while Japan uses the PDC standard. Naturally, Nokia's effective use of platforms in the GSM 900 market complements these global platforms.

Nokia's advantages in development efficiency from creating global platforms can be estimated using estimates on the percent of product designs that are common within each series. Of the five firms who provided data (Nokia, Ericsson, Motorola, Mitsubishi, NEC, and Matsushita), only Nokia and to a lesser extent Ericson use common designs across standards. As shown in Table IV, there are large amounts of commonality between standards for each of Nokia's product lines (this data only shows the percent common among the GSM and TDMA phones). Assuming that half of the noncommon designs are unique for each phone, the number of equivalent projects needed to modify the GSM 900 platforms for the GSM 1800 and 1900, TDMA 800 and 1900, and the PDC markets are shown in Table IV. For a total of 3.5 additional "equivalent" projects, Nokia was able to introduce 17 new phones during these years, a number that is several times larger when one considers the number of different languages and other regional permutations.

Nokia also uses the GSM 900 platforms to develop cdmaOne phones. Although this is not shown in Fig. 6, cdmaOne 2170 was developed from the 2110 GSM 900 platform and the cdmaOne 6100 was based on the GSM 900 6110. There is of course less commonality between the cdmaOne and GSM 900 phones than between the GSM, TDMA, and PDC phones since the latter three standards are all based on TDMA technology [11]. In general, the baseband designs are a function of the air-interface standard while the radio-frequency designs are a function of the frequency band (e.g., 800 MHz). Nevertheless, there is still some level of commonality in all the design categories shown in Table IV (at least half the figures shown in Table IV) with the greatest level of commonality in the mechanics.

Ericsson was about half way between Nokia and the other firms in terms of the use of common designs during the late 1990s. Although it had almost no commonality between baseband chips, radio-frequency designs and board layouts, there was strong commonality in mechanics and to some extent in software. The interviews suggest that if Ericsson were to have developed the same phones as Nokia, they would have had the same commonality as Nokia in mechanics, three-quarters

[14]See for example, Nikkei Industrial, June 18, 1998, "Bei VLSI tekunoroji-shinhoshiki keitai denwa no kinou, 1 chippu ni tosai—nihonmuke tounyu (The U.S. firm VLSI technologies will introduce a chip for the new mobile phone system in Japan)."

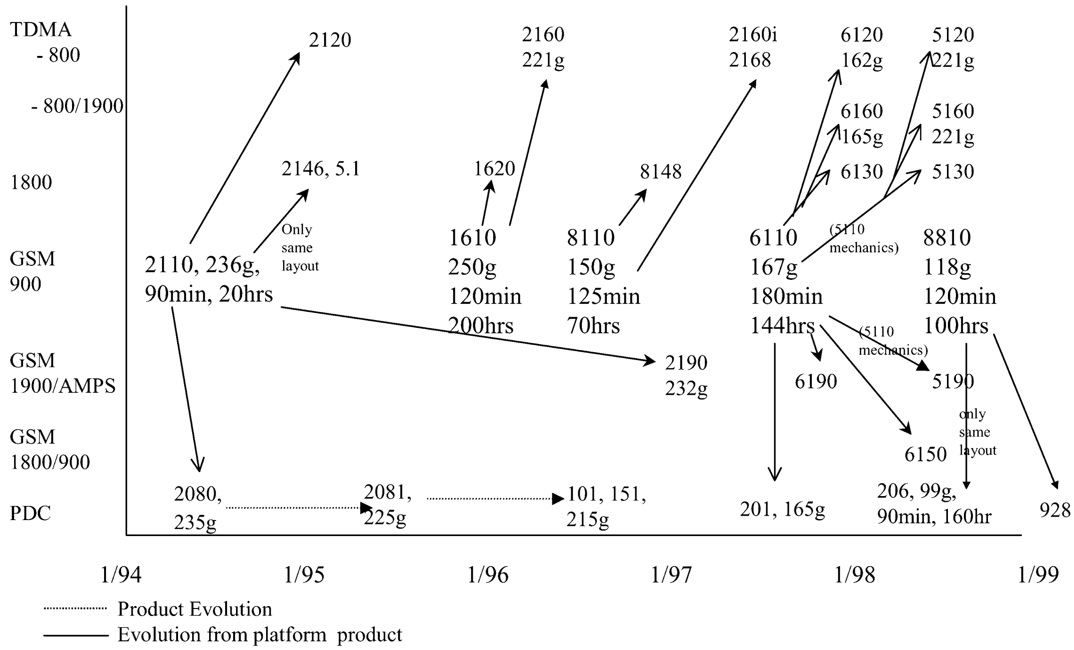

Fig. 6. Evolution of Nokia's global platforms.

TABLE IV
PERCENT OF COMMON DESIGNS IN NOKIA'S DIGITAL PHONES BY SERIES ACROSS DIFFERENT STANDARDS (TDMA, PDC, GSM) AND FREQUENCIES (800, 900, 1800, 1900)

Series	Architecture	Baseband	Radio Frequency	Board layout	Mechanics	Software
2110	100%	50%	50%	50%	80%	50%
1610/ 8110	100%	50%	50%	50%	80%	50%
6110	100%	50%	50%	50%	100%	50%
5110	100%	50%	50%	50%	100%	50%

Source: [10].

TABLE V
AMOUNT OF ADDITIONAL DEVELOPMENT RESOURCES IN EQUIVALENT DEVELOPMENT PROJECTS NEEDED TO MODIFY NOKIA'S 900 PLATFORMS FOR PHONES SHOWN IN FIG. 2

Series	Nokia	Motorola and the Japanese Firms	Ericsson
2110	0.76	2.38	1.26
1610/8110	0.57	1.38	1.20
6110	1.31	2.66	1.75
5110	0.87	1.44	1.09
Total	3.51	7.86	5.30

Source: [10].

the commonality in software, and half the commonality in architecture.

Using these estimates of the percent of common designs across standards, Table V also contrasts Nokia's development numbers with those of other firms. It estimates the amount of additional development resources (units are equivalent development projects) that would be needed to modify Nokia's 900 platforms for the markets and phones shown in Fig. 6 if other firms attempted to do so. Table V shows that Motorola and the Japanese firms would have required almost twice the level of development resources as Nokia to introduce the same phones primarily since Motorola and the Japanese firms developed independent platforms for each standard and, thus, they used no common designs *between* different standards.

VI. DISCUSSION

This paper had two goals: 1) to understand how product line management evolves over the life of an industry and 2) to compare Klepper's model with the traditional model of the product life cycle. We find that Klepper's product life cycle model in combination with methods of product line management provides a better explanation for the evolution of competition in the mobile phone industry than the traditional product life cycle that emphasizes the emergence of a dominant design.

Extrapolating from a single case is very problematic. As discussed in the introduction, mobile phones have a large variety of and fast rate of change in both families and models and, thus, they occupy the upper right corner of Uzumeri and Sanderson's framework [30] for patterns of model and family evolution. Products that fall in this quadrant may follow a similar pattern of platform management that has been described in this paper for mobile phones; a pattern that depends on volumes, costs, and economies of scale. In this pattern, most new industries initially exhibit a slow change in volumes and costs and, thus, competition initially often focuses on quality and performance. This was the case in the 1980s when a large number of firms held relatively equal shares of the U.S. AMPS and NMT markets.

However, as growth accelerates, there is often a synergistic effect between rising volumes and falling prices. The analysis of the mobile phone industry suggests that the length of the transition period from low to high growth and the relative importance of volume-sensitive parts to phone cost and weight are key variables that impact on the appropriate product line and platform strategy in this growth phase. When the transition from the low-growth to high-growth phase takes place over a number of years (about five years in the U.S.) and volume sensitive parts represent a large percentage of phone costs, the winner is often the firm who can turn the volume wheel the fastest. This was how Motorola came to dominate the AMPS and to some extent the NMT markets. It gave volume discounts to increase volumes and, thus, received volume discounts from suppliers. This was particularly effective since volume sensitive parts such as semiconductor devices represented a large percentage of the product cost.

In GSM, the transition from the low-growth to high-growth phase happened so quickly that the market had evolved into a second stage of multiple segment competition before one firm could win the volume discount battle. Further, the key drivers of cost and performance had changed from very volume sensitive parts such as semiconductors to less-volume sensitive parts such as mechanical parts. Both of these factors meant that Motorola's volume discount strategy was much less effective in the GSM than in the AMPS markets.

The multiple-price-segment GSM market may be typical of the emerging network economy where there are high-fixed and low-marginal costs [25]. The spread of these high-fixed and rapidly declining marginal costs from the service-side of the network economy to the manufacturing-side of the network economy may be changing the way manufacturers carry out product line/platform management. The platform products used by Motorola, Ericsson, and Nokia to develop derivative products represent the high-fixed costs of the network economy. These high-fixed costs of course require large volumes and, thus, these three firms subsidize the low-end phones in order to obtain high volumes. Further, these high-fixed costs and their required high volumes represent a barrier to entry for other firms. These three firms, particularly Nokia, make money at the high-end of the market by creating a strong brand image. Nokia has created a stronger brand image than the other firms by focusing on aesthetic design, user interfaces, and software features. Its success in these areas enables it to set prices that are based more on customer value than on cost.

Global platforms may represent the ultimate platform strategy and as most industries globalize, this strategy may become even more prevalent and important to success. Nokia's use of global platforms improved its development and manufacturing efficiency and changed the competition from competition within a single market, including its specific user needs and other idiosyncrasies, to competition at the global level in much that same way that Sony did with its Walkman [23]. Both Nokia and Sony introduced more models than their competitors by using platform and derivative projects at the global level more effectively than their competitors. They also did this using a network of development centers albeit Sony's decentralized development was only for industrial design while Nokia introduced a network of technology development centers.

One unique aspect of Nokia's approach is that in creating global platforms it was actually redefining the product families. While the industry had traditionally defined families in term of standards and firms had organized their development accordingly, Nokia recognized the greater similarities between digital than between analog standards and, thus, the ability to redefine families in new ways. Interestingly, it was more successful in doing this than Ericsson was in redefining the market concepts that form the basis for defining new models. This provides further evidence that market uncertainty is often larger than technological uncertainty.

Further research should look at other products to compare Klepper's model with the traditional model of the product life cycle. For example, PCs and PDAs represent product with long transitions from the low-to high-growth phase (assuming the PDA every reaches a high-growth phase) while DVDs represent a product with a very short transition, apparently the shortest in history [17]. Further, dominant designs have played and continue to play an important role all of these products. For example, while the emergence of the Wintel (originally called IBM standard) standard significantly changed competition in the industry, subsequently rising volumes and new distribution methods further changed competition in the industry. It is likely that similar effects will be felt by the PDA industry.

Further research should also test Klepper's hypotheses about product and process R&D. Although we did not directly test these hypotheses, data on Motorola, Nokia, and Ericsson phones in the GSM market suggests that this market does partly follow his hypotheses as long as innovations in semiconductors and discrete components are defined as process innovations. As in the PC and PDA industries, phone innovations are primarily driven by the emergence of smaller and cheaper semiconductors and discrete components, which are in turn due to process innovations in these industries. On the other hand, this definition of process innovations explains a growing concentration of firms in the semiconductor and discrete component industries and not in the phone industry. Further research should illuminate these and other issues that have been identified in analyses of the product life cycle theory.

REFERENCES

[1] W. W. Alberts, "The experience curve doctrine reconsidered," *J. Marketing*, vol. 53, no. 3, pp. 36–49, 1989.

[2] W. Abernathy and J. Utterback, "Patterns of innovation in technology," *Technol. Rev.*, vol. 80, pp. 40–47, July 1978.

[3] W. Abernathy and K. Clark, "Innovation: Mapping the winds of creative destruction," *Res. Pol.*, vol. 14, pp. 3–22, 1985.

[4] P. Anderson and M. Tushman, "Technological discontinuities and dominant designs: A cyclical model of technological change," *Adm. Sci. Quart.*, vol. 35, no. 4, pp. 604–633, Dec. 1980.

[5] *Perspectives on Experience*. Boston, MA: Boston Consulting Group, 1972.

[6] A. Chandler, *Scale and Scope: The Dynamics of Industrial Capitalism*. Cambridge, MA: Harvard/Belknap, 1990.

[7] M. Cusumano and K. Nobeoka, *Thinking Beyond Lean: How Multi-Project Management is Transforming Product Development at Toyota and Other Companies*. New York: Free Press, 1998.

[8] J. Dutton and A. Thomas, "Treating progress functions as managerial technology," *Acad. Manage. Rev.*, vol. 9, pp. 235–247, 1984.

[9] K. Frenken, P. Saviotti, and M. Trommetter, "Variety and niche creation in aircraft, helicopters, motorcycles and microcomputers," *Res. Pol.*, vol. 28, pp. 469–488, 1999.

[10] J. Funk, *Global Competition Between and Within Standards: The Case of Mobile Phones* London, Palgrave, U.K., 2001.

[11] G. Garrard, *Cellular Communications: Global Market Development*. Norwood, MA: Artech House, 1998.

[12] A. Gawer and M. Cusumano, *Platform Leadership: How Intel, Microsoft, and Cisco Drive Industry Innovation*. Boston, MA: Harvard Business School, 2002.
[13] M. Hobday, “Product complexity, innovation and industrial organization,” *Res. Pol.*, vol. 26, pp. 689–710, 1998.
[14] D. Hounshell, *From American System to Mass Production, 1800–1932: The Development of Manufacturing Technology in the United States*. Baltimore, MD: The Johns Hopkins Univ. Press, 1984.
[15] S. Hulten and B. Molleryd, “Mobile telecommunications in Sweden,” in *Mobile Telecommunications: Emerging European Markets*, K. Schenk, J. Muller, and T. Schnoring, Eds. Norwood, MA: Artech House, 1995.
[16] S. Klepper, “Entry, exit, growth, and innovation over the product life cycle,” *Amer. Econ. Rev.*, vol. 86, no. 3, 1986.
[17] R. Lyman, *Revolt in the Den: DVD Sends the VCR Packing to the Attic*: New York Times, 2002.
[18] J. Meurling and R. Jeans, *The Ugly Duckling: Mobile Phone From Ericsson—Putting People on Speaking Terms*. Stockholm, Sweden: Ericsson Mobile Communications AB, 1997.
[19] M. Meyer and A. Lehnerd, *The Power of Product Platforms*. New York: Free Press, 1997.
[20] D. Montgomery and C. Day, “Experience curves: Evidence, empirical issues and applications,” in *Strategic Management and Marketing*, D. M. Gardner and H. Thomas, Eds. New York: Wiley, 1984.
[21] D. Mookherjee and D. Ray, “Collusive market structure under learning-by-doing and increasing returns,” *Rev. Econ. Stud.*, vol. 58, no. 5, pp. 993–1009.
[22] M. Porter, “The technological dimension of competitive strategy,” in *Research on Technological Innovation, Management and Policy*, R. Rosenbloom, Ed. Greenwich, CT: JAI, 1983.
[23] S. Sanderson and V. Uzumeri, “Managing product families: The case of the sony walkman,” *Res. Pol.*, vol. 24, pp. 761–761, 1995.
[24] H. Shosteck and Associates, “The Retail Market of Cellular Telephones,” Quarterly Survey, Sept. 1996, Wheaton, MD, vol. 13, no. 4, 1997.
[25] C. Shapiro and H. Varian, *Information Rules*. Boston, MA: Harvard Bus. School Press, 1999.
[26] P. Smith and D. Reinertsen, *Developing Products in Half the Time: New Rules*, 2nd ed., 1997.
[27] D. Teece, “Profiting from technological innovation: Implications for integration, collaboration, licensing, and public policy,” *Res. Pol.*, vol. 15, pp. 285–285, 1986.
[28] K. Ulrich and S. Eppinger, *Product Design and Development*, New York: McGraw-Hill, 1995.
[29] J. Utterback, *Mastering the Dynamics of Innovation: How Companies Can Seize Opportunities in the Face of Technological Change*. Boston, MA: Harvard Bus. School Press, 1994.
[30] V. Uzumeri and S. Sanderson, “A framework for model and product family competition,” *Res. Pol.*, vol. 24, pp. 583–607, 1995.
[31] S. Wheelwright and K. Clark, *Revolutionizing Product Development: Quantum Leaps in Speed, Efficiency, and Quality*. New York: Free Press, 1992.
[32] P. Windrum and C. Birchenhall, “Is product life cycle theory a special case? dominant designs and the emergence of market niches through co-evolutionary-learning,” *Struct. Change Econ. Dyn.*, vol. 9, pp. 109–134, 1998.

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