SEPPÄLÄ, T, & ALI-YRKKÖ, J, **NOKIA AND THE EVOLUTION OF MOBILE TELEPHONY.**

ABSTRACT: In the late 1980s, Nokia was a conglomerate with a number of subsidiaries in different sectors. As a response to heavy losses in the early 1990s, the company divested all other activities and focused on cellular network equipment and mobile handsets. After rapid growth in the late 1990s, Nokia became the market leader in handsets in 1998. In Q4 2007, Nokia's estimated global market share peaked at 40%. Since that time, its market share has dropped to approximately 25%. In this article, we discuss the changing fortunes of Nokia in the elusive landscape of mobile telephony. Our analysis is based on a wealth of detailed micro-level data for Nokia and the industry at large and over one hundred interviews with industry experts.

KEY WORDS: Industry evolution, global value chains, strategic decision making

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*Nokia is nothing less than a national institution in Finland because of its contribution to the national economy and its long history, but the keen interest in the company today stems more from its recent success as Finland's first real world-class corporation. (*Häikiö, 2003 p. 13)

1. INTRODUCTION

In 1990, mobile phones were luxury products mainly targeted at business users. Today, almost every adult in the developed world owns a mobile phone, and more than one billion units are sold every year.

The competitive landscape has changed drastically during the past 20 years. In 1990, Motorola was the market leader, with 22 % of the global market share. Other major players were Nokia, NEC, Novatel and Panasonic (Häikiö 2001, p. 25). Ten years later, Motorola had lost its position to Nokia. Today, the competitive landscape has changed again, as new competitors continue to challenge Nokia.

In this article, we discuss the changing fortunes of Nokia in the elusive landscape of the mobile phone industry by focusing on the period from 2001 to 2011. The main questions addressed in this article include the following. 1) How has Nokia succeeded in the global market? 2) What has been Nokia's role in the Finnish economy? 3) What are the critical factors for controlling the value of the handset value chain in the future?

Our analysis is based on detailed empirical data of Nokia's products, the geographical distribution of the value of products in Nokia's global supply chain and the latest patenting trends related to computing, telecom, software and heuristics. Furthermore, we obtained qualitative data through more than one hundred interviews with industry experts.

The article is arranged as follows. Chapter 2 briefly describes Nokia's evolution, focusing on market changes and Nokia's situation in the 1990s and today. Furthermore, the role of Nokia in the Finnish economy is discussed. Chapter 3 synthesizes and summarizes the major results and findings of our previous articles and analyses related to value creation in handsets, knowledge transfer in emerging countries and changing patenting trends (see Hyytinen et al., 2006, Ali-Yrkkö, 2010, Ali-Yrkkö et al., 2011, Ali-Yrkkö & Seppälä, 2011 forthcoming and Seppälä & Martikainen, 2011 forthcoming). Chapter 4 explains the current layout of Nokia's global supply chain and introduces the new industry value chain structure. The article concludes with reflections.

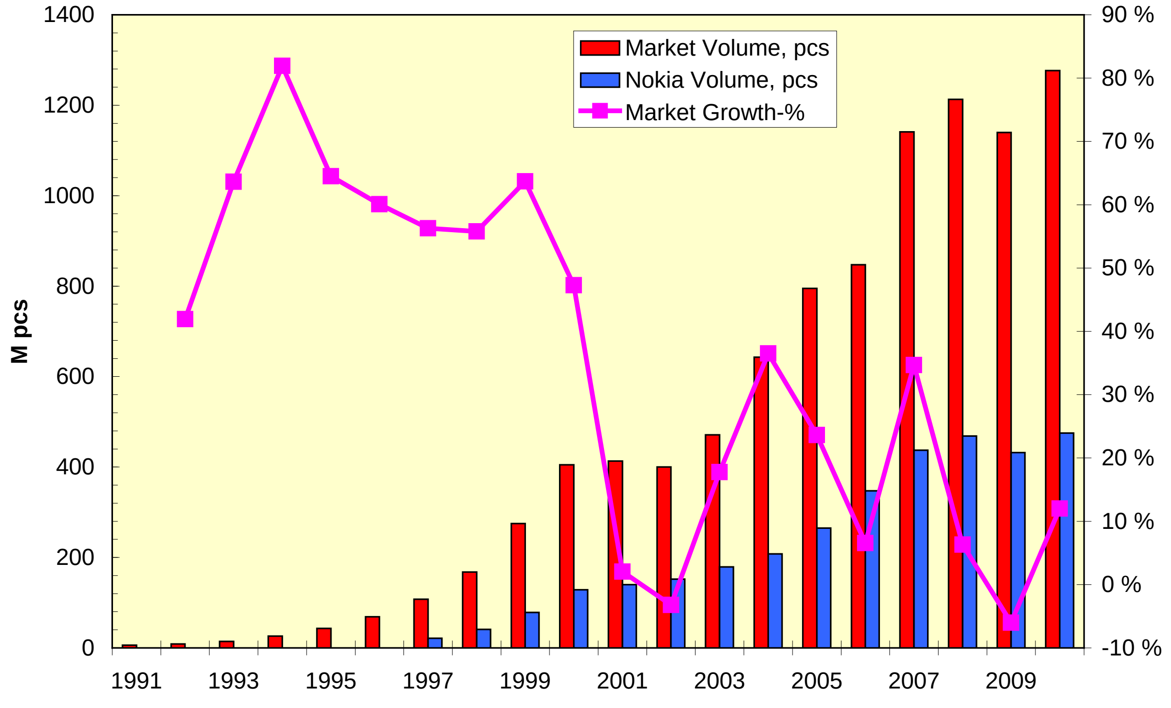
2. FORTUNE FAVORS THE BRAVE

In the late 1980s, Nokia was a conglomerate, with business units in various sectors. As a response to heavy losses in the early 1990s, Nokia abandoned its old strategy and made a brave decision to focus only on telecommunications. As a result of this decision, Nokia divested businesses that generated 70% of its net sales.

During the late 1990s, its booming telecommunications business pushed Nokia to rapid growth, with a growth rate of more than 30 % a year. Hence, the company's risky focus strategy proved successful. Nokia's success continued in the early 2000s. In 2007, Nokia claimed as much as 40% of the global handset market. However, the market was changing, and new competitors, such as Apple and Google, were entering the market. Systems from Apple and Android, the mobile operating system from Google, attracted an increasing number of consumers. As a result, Nokia’s market share decreased in 2008.

Figure 1 describes the development of the global mobile phone market and Nokia’s handset sales. It also shows the average global market growth of mobile phones in percentage.

Figure 1: Global mobile phone sales, global Nokia sales and global market growth.



Source: ETLA

Nokia was not the only Finnish company in trouble in the early 1990s. The entire Finnish economy underwent a deep depression, as its GDP dropped approximately 14% and unemployment rose to almost 20% (Honkapohja & Koskela 1999). Due to devaluation of the Finnish currency, the price competitiveness of Finnish industries improved and export-driven recovery began. During the latter half of the 1990s, the Finnish economy enjoyed exceptionally rapid growth rates. The average GDP growth rate exceeded 4.5%, a rate well above the average growth in most OECD countries.

Nokia contributed increasingly to this GDP growth (Table 1). While Nokia's contribution to GDP growth was 0.4 percentage points in 1995, the corresponding figure peaked at 2.1 percentage points in 2000 when the total GDP growth was 5 percent. Consequently, Nokia was responsible for approximately 40% of the total GDP growth in 2000. After the peak year of 2000, Nokia's contribution to growth has varied. In some years, such as 2009, its contribution has been negative. However, the most recent figure for 2010 was positive.

Notwithstanding its decreasing contribution to GDP growth, Nokia is still the single most important single company in the Finnish economy[1]. However, it is unlikely that its role in the Finnish economy will be restored to former levels.

Table 1: The relationship between Nokia and the Finnish economy.

	1995	2000	2010
Share of GDP, %	1.1 %	4.0 %	1.2 %
Contribution to GDP growth, %-points	0.4 %	2.1 %	0.4 %
Share of total R&D expenditure, %	14.5 %	30.4 %	32.3 %
Share of corporate taxes, %	4.0 %	14.2 %	3.3 %
Share of total exports,%	8.5 %	20.7 %	14.2 % (2009)

Source: ETLA

In some ways, Nokia's crisis in the 1990s and its current situation are similar. After years of success, the old strategy no longer works. In the early 1990s, Nokia focused on telecommunications by divesting all other business units. In February 2011, Nokia announced that it will desert its operating system Symbian. The old Symbian operating system S60 will be completely replaced by MS7, a Microsoft operating system.

One potential reason for Nokia's current difficulties is management; during the 2000s, Nokia may have focused too heavily on cost efficiency[2]. However, in principal, Nokia correctly foresaw the future, as the following examples show. Three years before Apple launched its iPhone, Nokia launched its first touchscreen device, the Nokia 7700. In the next year, Nokia developed additional touchscreen models, but because of management decisions, these models never made it to the market. Another example is Nokia's Internet tablet, the 700, which was launched in 2005. This model did not leave the prototype stage, and unlike current tab-

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[1] In terms of share of GDP or share of R&D expenditures.

[2] Mary McDowell's interview in Talouselämä 15.4.2011. Mary McDowell is the executive vice president in charge of mobile phones and is responsible for the business and product development of Nokia's global mobile phone operations.

lets, the screen of this model was too small to surf easily on the Internet. Displays are one of the most expensive components of mobile phones (Ali-Yrkkö et al. 2011). These examples suggest that its low-cost strategy was one potential reason for Nokia's current difficulties.

Furthermore, important changes in Nokia's top management were made between 2005 and 2006. Several management team members left or were replaced by new management team members. Some of these changes occurred between 2005 and 2006, a period during which Nokia's patenting efforts began to decline in several technology areas, according to OECD PATSTAT (Seppälä & Martikainen, 2011, forthcoming). Both strategic and managerial problems at Nokia seemed to culminate in the years 2005 and 2006, but they only became visible five years later. All organizational changes at Nokia are described in detail in Appendix 1.

Nokia's current situation can also be considered to be technologically based. While 2G technologies are in the declining phase of their technological life cycle and 3G technologies are in the mature phase, opportunities are emerging for new competition. In addition to these cellular technology environments, operating system technologies, including UNIX (Apple), Linux (Google) and Microsoft (Microsoft/Nokia), and the ways in which these systems translate to new cellular technology environments must be considered.

Furthermore, Nokia's current difficulties began to deepen and become visible to the public in 2009, two years after the launch of Apple's iPhone[3]. Nokia has not been able to respond to Apple's and Google's challenges of introducing touch screen phones in the US market. After the introduction of the iPhone and other similar mobile phones with advanced user experiences, the market began to shift away from hardware and software centricity and toward software and advanced user experience centricity.

3. GLOBAL VALUE CHAINS OF MOBILE PHONES

In this chapter, we discuss mobile phones in detail. In the previous chapter, we considered Nokia's role in the Finnish economy. However, Nokia's economic impact is not limited to one country. Moreover, Nokia is only one part of the global phone supply chain, excluding the impacts of other supply chain participants.

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[3] http://www.apple.com/pr/library/2007/01/09iphone.html (information retrieved 26.4.2011)

We solidifies the operations of global value chains by taking a detailed look at four single products. The case of the Nokia N95 enables us to describe the current way in which Multination Enterprises(MNE's) operate globally. Another analysis focusing on the Nokia 3310, 1100 and 1200 cases enables us to describe changes in the business environments of MNEs during the last fifteen years and the ways in which knowledge of commoditized 2G technologies has been systematically transferred from advanced economies to emerging economies. The third case and our descriptive analyses based on the OECD patent database (PATSTAT) enable us to define a new market control mechanism for industry value chains. These robust empirical data enable us to understand key developments in a handset value chain, even when the empirical data are for only one MNE and four products.

3.1. Case N95

Global value chains operate at ever finer resolutions in terms of where, when and by whom individual tasks and processes of the MNE are executed (Baldwin, 2006, 2009; Ali-Yrkkö et al. 2011). The Nokia N95 is a typical example of a mobile phone product that requires a number of value creating tasks and processes, performed by a number of MNEs and in a number of locations within those MNEs (Ali-Yrkkö, 2010, Ali-Yrkkö et al., 2011). The N95 case solidifies the operations of such value creation processes from the perspective of a single product and a single time point[4].

In Tables 2 and 3, different value breakdowns for a single product are presented from both an industry value chain participant and a geographical perspective. The tables show the varying amounts of value captured by different participants associated with the N95 mobile phone.

[4] http://europe.nokia.com/support/product-support/nokia-n95 (information retrieved 25.5.2011)

Table 2: The value added breakdown of the N95 by supply chain participant, %.

	N95
Vendors of vendors	19%
Suppliers of material inputs	11%
Software and other companies selling licenses	3%
Nokia	50%
Distributors	3%
Retailers	11%
Unaccountable inputs	3%
Total	100%

Source: Ali-Yrkkö et al., 2011; ETLA database

Table 3: The value added breakdown of the Nokia N95 by major region, %.

	10% to the headquarter country and 90 % based on the locations of production factors, corrected for productivity
Finland	38.8 %
Other EU-27 countries	7.1 %
North America	8.9 %
Asia	6.4 %
Other countries	0.4 %
Unaccounted inputs	3.1 %
Vendors of vendors	18.7 %
The country of final sales	14.5 %
The country of final assembly (Finland or China)	2.1 %
	100%

Source: Ali-Yrkkö et al. 2011; ETLA database.

Note: Ali-Yrkkö et. al. (2011) presented 5 different alternatives to calculate added value by region. Table 3 presents the authors' preferred version. Our calculation method for Table 3 is described in Appendix 2.

The final row of Table 2 reveals an interesting result. The final assembly and manufacturing cost of the N95 is €11.5, which is only 2% of the pre-tax final sales price. Thus, notwithstanding the fact that final assembly is an essential part of the supply chain, the added value that it commands in the product is surprisingly low. Thus, if the N95 was assembled in Finland and sold in another country, Finland would capture 41.9% (38.8% + 2.1%) of the total value (Table 3). However, if the phone was assembled in China, Finland would still capture 38.8% of the value. These calculations reveal that the value of the product is mostly created in activities other than assembly. These other activities include a variety of white-collar jobs such as branding, marketing, design, patenting and sourcing.

As mentioned, the N95 case solidifies the operations of value creation process from the perspective of a single product and a single time point, but it also explains how the research and development and production networks of MNEs are scattered globally. Furthermore, we acknowledge the difficulties in managing such scattered networks.

3.2. Cases 3310, 1100 and 1200

The N95 case can be seen as a cross-sectional study without dynamic elements. To fill this gap, we consider three mobile phone models launched between 1999 and 2007[5]. These three models include similar functionalities and different designs. In particular, the 1100 and 1200 are basic models without any significant new features compared to older models, such as the Nokia 3310, and they are targeted at first-time users in entry markets[6,7,8]. This similarity offers an outstanding opportunity to consider the commoditization of technology and the geographical and organizational creation of value at the product level.

The Nokia 3310 mobile phone is a perfect example of a mobile phone that was once a high tech product in advanced economies in the early 2000s and is now a commodity. The N95 provides a similar example. The Nokia 3310, launched in 1999, can be considered the starting point of the systematic transfer of knowledge from Nokia to emerging economies. The Nokia 1100, launched in 2003, signifies a similar starting point in the transfer of knowledge, but this

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[5] This section is based on Ali-Yrkkö & Seppälä (Forthcoming).

[6] http://europe.nokia.com/support/product-support/nokia-3310 (information retrieved 25.5.2011)

[7] http://europe.nokia.com/support/product-support/nokia-1100 (information retrieved 25.5.2011)

[8] http://europe.nokia.com/support/product-support/nokia-1200 (information retrieved 25.5.2011)

case is based around a supplier collaboration perspective (see Seppälä, 2010). In addition to these two products, the Nokia 1200, launched in 2007, marks the latest stages in the systematic transfer of knowledge between advanced and emerging economies. Today, 2G-based technologies are completely conceptualized, designed, prototyped, manufactured, distributed and after-market serviced for emerging economies.

Table 4 show the results for these cases; the same methodology as that used in the N95 case was used.

Table 4: The value added breakdown for the Nokia 3310, 1100 and 1200 supply chains by participant, %.

	N95	**Nokia 3310**	**Nokia 1100**	**Nokia 1200**
Vendors of vendors	19%	22%	21%	34%
Suppliers of material inputs	11%	17%	17%	19%
Licensors	3%	0.5%	0.5%	0.8%
Engine manufacturing		5%	3%	2%
Nokia, excl. engine manufacturing	50%	38%	39%	19%
Logistics and warranty		2.5%	4.9%	6.4%
Distributor	3%	4%	4.4%	4.7%
Retailers	11%	10.6%	10.2%	13.6%
Unaccountable inputs	3%	0%	0%	0%
Total	100%	100%	100%	100%

Source: Ali-Yrkkö & Seppälä, forthcoming 2011; ETLA database

Table 4 reveals three notable observations. *First*, the most remarkable difference between the N95 smartphone and the basic models is Nokia's share. For the N95, Nokia accounted for half of the total value, while for the basic models, Nokia’s share was smaller. *Second*, Nokia's share has declined. In the case of the Nokia 3310, launched in 1999, Nokia accounted for almost 40% of the total value, but in the case of the Nokia 1200, its share was halved to 19%. *Third,* manufacturing costs have markedly decreased.

Next, we consider in detail the reasons why an increasing share of value is created overseas. Based on our interviews (for details, see Ali-Yrkkö and Seppälä 2011), Table 5 summarizes the locations of the main tasks related to different phone models.

Table 5. The location of tasks related to the 3310, 1100 and 1200.

Phone model	**Nokia 3310**	**Nokia 1100**	**Nokia 1200**
Product Life Cycle	1999 - 2003	2003 – 2007	2006 -
	including: 3310 (Europe), Chinese variant[9] (China), American variant [10] (USA)	including: 1100 (Asia & Europe), and its American variant[11] (USA)	
Product management	Denmark	Denmark	Denmark
Hardware platform design and development	Denmark, Finland	Denmark, Japan	Denmark, China
Software platform design and development (S30)	Denmark	Denmark	Denmark
Application services design and development (S30)	Denmark	Denmark	Denmark
Application design and development (S30)	Denmark	Denmark	Denmark
User interface design and development (S30)	Denmark	Denmark	Denmark
Product software design (S30)	Denmark, (Ladybird's software variant in China)	Denmark, (Indianhead's software variant in Finland)	Denmark, (active participation from China)
Concept design	Finland; Denmark	Finland; Denmark	Finland; China
Product design (HW)	Denmark (3310), Finland (American variant)	Denmark (1100), Finland, USA (A variant)	China
Product test design	Finland	Finland	China
Proto manufacturing	Finland, USA	Finland, USA	China
ATO (Nokia)	USA, Finland, Germany, Hungary, China, South Korea	USA, Hungary, China, South Korea, Brazil	China, India, Romania, Hungary, Mexico, South

[9] Software variant in the Asian market

[10] American variant requires a close collaboration with American hardware and software operators

[11] American variant requires a close collaboration with American hardware and software operators

			Korea
Engine assembly if not in ATO location (Nokia)		Mexico	

Source: Ali-Yrkkö & Seppälä, forthcoming 2011; ETLA database

Table 6 confirms that an increasing number of job tasks are located in Asia, particularly in China. The 3310 was mostly produced in Europe. Product management and nearly all design tasks were located in Europe, in Denmark and Finland. Nokia not only manufactured prototypes in developed countries but also mass manufactured this model partly in Europe and the U.S. The 3310s were also manufactured in China and South Korea. From Nokia's viewpoint, the 3310 was its first global product, as it was manufactured and sold on three continents.

The relocation of tasks related to these products has been gradual. In the case of the 1100, the majority of mass manufacturing was located in lower cost countries, whereas the more demanding tasks, typically related to hardware and software design, were located in developed countries, mostly in Denmark and Finland. Several years after the launch of the 1100, Nokia introduced the 1200 model, for which the role of China increased. Tasks such as prototype manufacturing, product hardware design and product test design were relocated to China. Furthermore, China also actively participated in concept design and product-specific software design. Based on our interviews, this relocation of tasks was part of Nokia’s goal to decrease the costs of its basic models. By cutting costs, Nokia would be able to decrease the final price for consumers, which in turn, would increase demand for the models.

As mentioned, the cases of the Nokia 3310, 1100 and 1200 solidify the operations of value creation processes from the perspective of multiple products and multiple time points, but they also explain industry dynamics as the technological life cycle progresses from emerging to mature to declining. Furthermore, we acknowledge the industry value chain shift from advanced economies toward emerging economies (Mudambi, 2008).

3.3. Changes in control mechanism of a mobile phone value chain

In the 1990s, the development of mobile telephone technology focused on building global telephony and data connectivity and solving the systematic problems of such automated networks (Seppälä & Martikainen, forthcoming 2011).

The hardware and software technologies of networks and mobile phones (Figure 1, circle 1) were the main points for controlling the value added logistics in industry value chains. Currently, the significance of applications and content is increasing, but content, as such, is not patentable. Thus, device manufacturers were faced with the challenge of controlling and capturing value from content. Patenting the ways of showing content to consumers is one solution (Figure 1, circle 2). In contrast to European patenting system, the US patenting system allows heuristic patents, which entails the patenting of known methods of human behaviour (Seppälä & Martikainen, forthcoming 2011). Apple's US patent number 7,479,949[12] is an example of patenting a known method of human behaviour[13]. This changing trend in patenting has been visible in OECD PATSTAT since 2005/2006.

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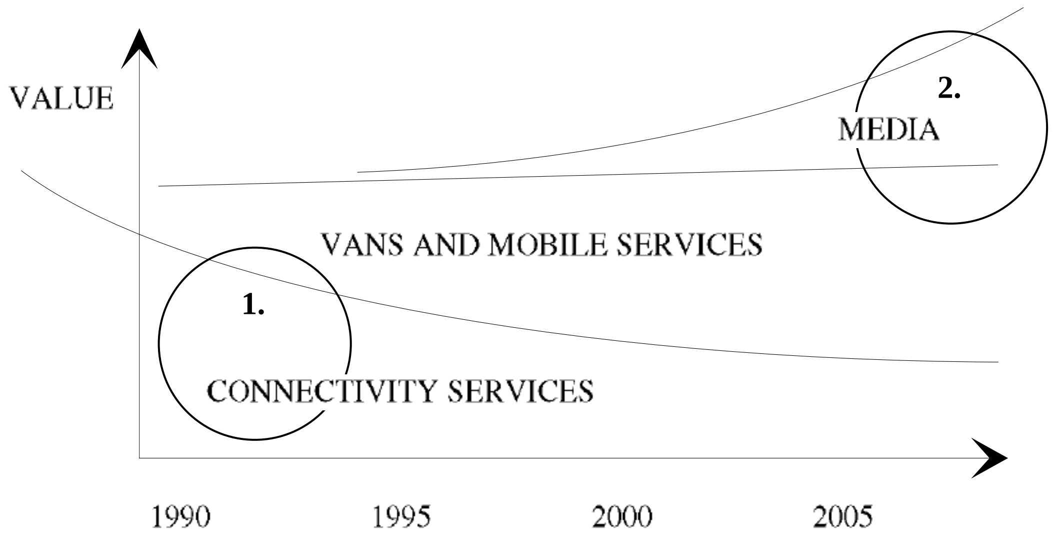
[12] http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=7,479,949.PN.&OS=PN/7,479,949&RS=PN/7,479,949 (information retrieved 6.4.2011)

[13] This known method of human behaviour, which reflects a computer-implemented method for use in conjunction with a computing device with a touch screen display, consists of detecting the contact of one or more fingers with a touch screen display, applying one or more heuristics to the one or more finger contacts to determine a command for the device, and processing the command. The one or more heuristics consists of heuristics for determining that the one or more finger contact correspond to a one-dimensional vertical screen scrolling command, determining that the one or more finger contacts correspond to a two-dimensional screen translation command and determining that the one or more finger contacts correspond to a command to transition from displaying an item in a set of items to displaying the next item in the set of items (Apple patent 7,479,949).

Figure 5: The shift in value creation in global value chains.



Source: Seppälä & Martikainen, forthcoming 2011

Changes in a firm’s patenting focus can be explained by a firm's recognition that the value in mobile phones has moved away from basic network and mobile technologies to services, applications and content. Previously, these technologies were standardized, developed and patented by the network equipment and mobile device manufacturers. The services are typically provided by mobile network operators, and the applications and content are typically provided by application and content providers; however, content, as such, is not patentable. The applications and content are marketed through mobile devices, and often operators, device manufacturers and operating system providers can only control the user interface and user experience features related to the applications and content in a device. Patenting known methods of human behaviour has enabled hardware and software firms to sidestep the existing patent portfolios of dominant firms; in fact, this is perhaps the only way of dismantling such dominance and creating a competitive advantage in 2G and 3G technology environments. Patenting competition is now expected to occur around LTE and 3D technologies.

4. EMERGING GLOBAL VALUE CHAIN STRUCTURES AND REFLECTIONS

In this article, we identified the three major shifts in the evolution of cellular telephony during the 20th century in relation to Nokia. All three shifts are important, but the last is the most relevant for defining the structure of the heuristics-controlled industry value chain. 1) In our Nokia N95 analyses, we described the current ways by which multinational enterprises operate in global value chains from a single product perspective. 2) The Nokia 3310, 1100 and 1200 analyses enabled an understanding of the business environment changes during the last fifteen years and the ways in which knowledge of commoditized technologies has been systematically transferred from advanced economies to emerging economies. 3) OECD PATSTAT patent data trends for Nokia from 2001 until 2009 enabled an understanding of the disturbances in Nokia's current business environment and also clarified developments in the control mechanisms of industry value chains in which content is controlled by the patenting of heuristics. This latest shift has supported the other evolutionary shifts of cellular telephony.

The main contribution of this article is related to the shift in control of mobile telephone industry value chains, which has not been previously understood or identified. We believe that by understanding the developments of industry value chains through product level analyses and by analyzing recent innovations through firm-level patent portfolios, we are capable of understanding changes in product-level geographies and of identifying possible changes in industry value chain control mechanisms. However, the future is not black and white, and disruptions can occur at anytime. Furthermore, the complexity of the business environment and industry dynamics in general will change as new hardware and software firms emerge.

The recent changes in firm strategies, existing value chain structures and the increasing patenting of heuristics indicate that the control mechanisms of value chains are shifting away from hardware- and software-based mechanisms and toward content-controlled heuristic mechanisms. This shift is described in Figures 2 and 3. Prior to 2007, value chains were controlled by the hardware and software participants of value chains. However, we believe that the new value chains will be controlled by the participants who control content through heuristics.

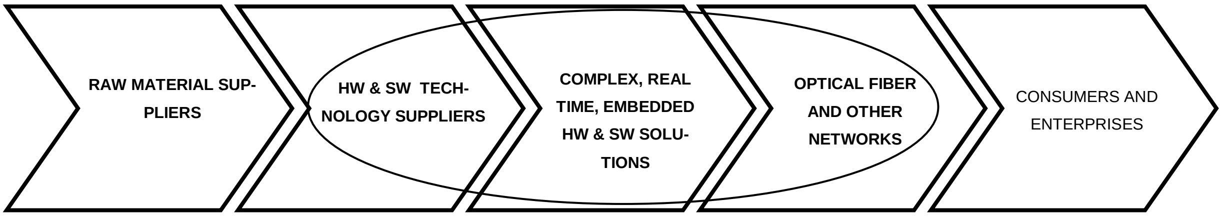


Figure 2: Hardware- and software-controlled global value chains.

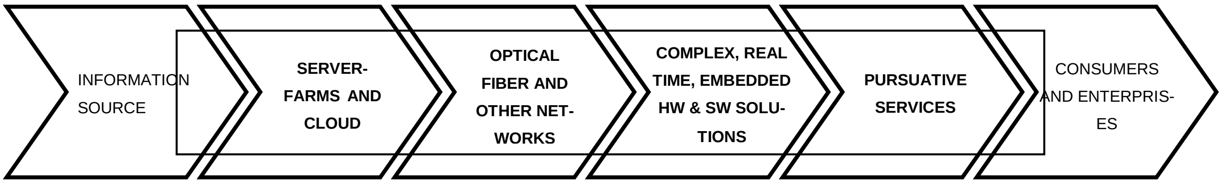


Figure 3: Heuristics-controlled global value chains.

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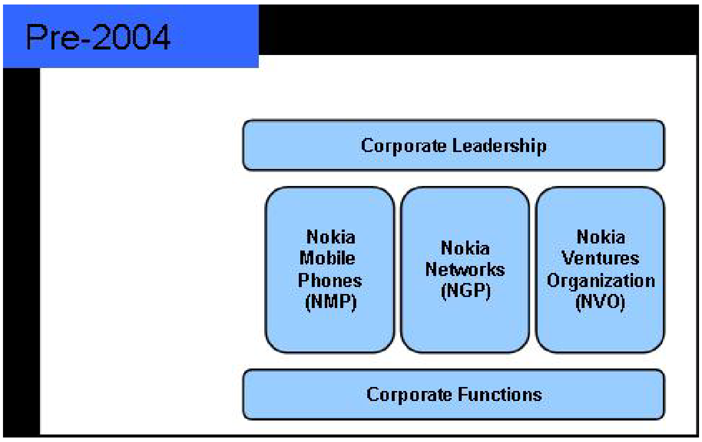
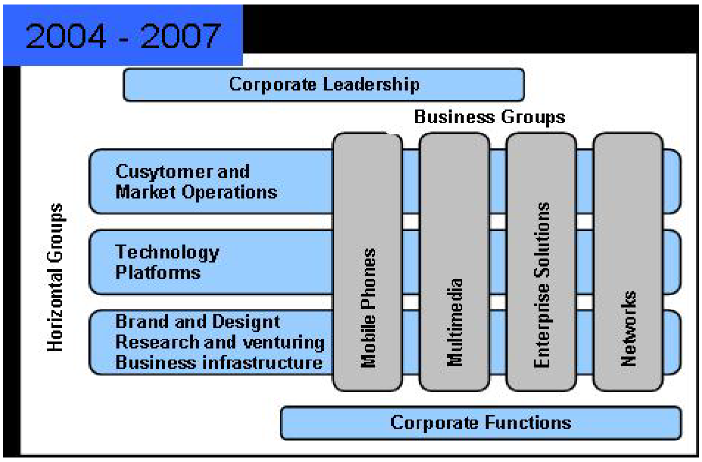
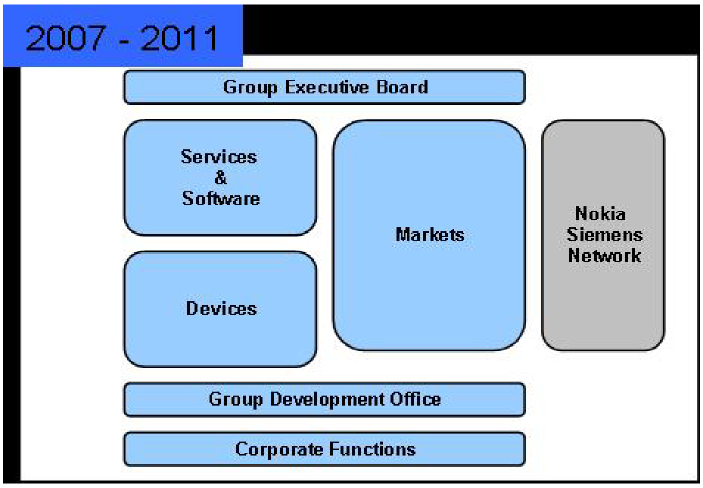
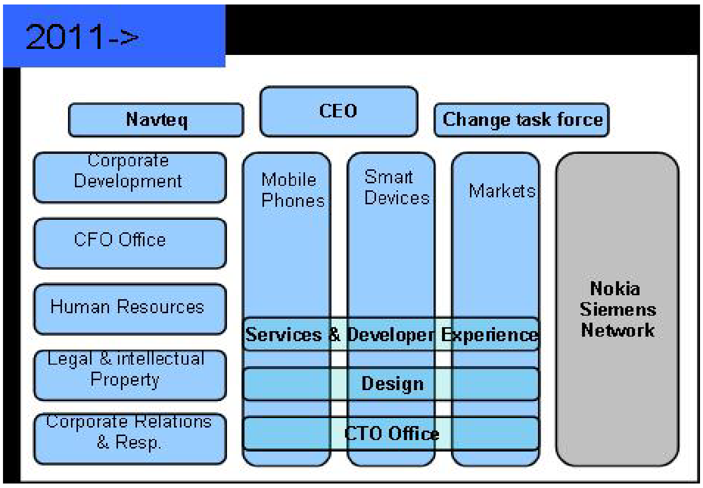
APPENDIX 1

This appendix was derived by the authors from the earlier version of Doz and Kosonen (2008). It describes changes in Nokia's organization from 2000 until spring 2011. Paija (2001) and Rouvinen and Ylä-Anttila (2006) described the earlier evolution of the Finnish mobile communications industry in separate publications.






2007 - 2011
Group Executive Board
Services & Software
Devices
Markets
Nokia Siemens Network
Group Development Office
Corporate Functions


2011->
Navteq
CEO
Change task force
Corporate Development
CFO Office
Human Resources
Legal & intellectual Property
Corporate Relations & Resp.
Mobile Phones
Smart Devices
Markets
Services & Developer Experience
Design
CTO Office
Nokia Siemens Network

APPENDIX 2

To estimate the geographical breakdown of the product's value, we proceed as follows. The total value of the product Y is composed of the value added of all parts of the product's value chain or

$$Y = \sum_{c=1}^{N} Y_c \ , \qquad (1)$$

where

Y = The total value of the product

Y_c = The value added of value chain's part *c*.

The value added of each part (Y_c) can be created globally. We assume that this total value added of each part is created in an area covering home country (Finland), other Europe, North-America and Asia, thus

$$Y_c = Y_{c,D} + Y_{c,E} + Y_{c,N} + Y_{c,A} + Y_{c,O} \ , \qquad (2)$$

where

D = Domestic (Finland)

E = Europe (Other EU-15)

N = North-America

A = Asia

0 = Others

Our data includes the value add of each part (Y_c) but we do not have information how this value added is created in different areas. To estimate the value added of part *c* created in each region ($Y_{c,D}, Y_{c,E}, Y_{c,N}, Y_{c,A}, Y_{c,O}$), we have proceed as follows.

We assume that the value added of part *c* captured in each region is created through factors of production. As usually in the economic literature, we consider three factors of production: physical capital stock (C), the size of labour force (*L*) and knowledge capital stock (K). We assume the impact of each production factor is the same as their elasticities of output. The previous empirical literature including a number of studies has estimated a Cobb-Douglas style of production function:

$$Q = AC^{\alpha} L^{\beta} K^{\gamma} \quad , \qquad (3)$$

where *A*= multiplicative technology parameter

The equation (3) is typically estimated in logarithm form thus the parameters α, β and γ are the elasticities of output (*Q*) with respect to physical capital stock, labour and knowledge, respectively. In the majority of empirical studies, the estimated production function has included only two factors of production: physical capital and labour. Usually, the results of empirical studies show that the physical capital elasticity is about 0.4 and labour elasticity about 0.6.

In studies, where knowledge capital is approximated by using R&D stock, the estimated knowledge capital elasticity varies typically between 0.05 - 0.25 (e.g. Hall 1993, Mairesse & Hall 1994, Harhoff 1998, Capron & Cincera 1998). Based on these studies, in our calculations we assume that this elasticity is 0.15. However, most of studies have not taken into account the double counting related to R&D. R&D investment also consists of investment in physical capital and labour and these components are included in the regular production factors (see e.g. Schankerman 1981, Hall & Mairesse 1996). Based on earlier literature, we know that roughly 50 percent of R&D expenditure are labour costs (Hall 2009, NSF 1995). By taking this fact into account, we modify the capital elasticity (0.6) and labour elasticity (0.4) as follows.

$$\hat{\alpha} = \alpha - 0.5\gamma$$

$$\hat{\beta} = \beta - 0.5\gamma$$

Thus, our double counting corrected elasticities for capital, labour and R&D are 0.325, 0.525 and 0.15, respectively. We use these elasticities as the multipliers of production factors.

We continue by calculating what share of each production factor is located in each region *R* and then multiply each share by the elasticity of output. Then we sum these values by region and obtain each region's share of value added (related to part *c*). Finally, we multiply this share by the value added of part *c* (Y_c). The value added of part *c* created in region R, is calculated as follows

$$Y_{c,R} = \left(\frac{C_R}{C} \hat{\alpha} + \frac{L_R}{L} \hat{\beta} + \frac{K_R}{K} \gamma \right) Y_c \tag{4}$$

, where

C_R is firm's physical capital stock in region *R*,

C is the sum of firm's physical capital in all regions,

L_R is firm's employment in region *R*,

L is the sum of firm's employment in all regions,

K_R is firm's knowledge capital in region *R*,

K is the sum of firm's knowledge capital in all regions,

Thus, for instance the domestically created value added is calculated as follows:

$$Y_{c,D} = \left(\frac{C_D}{C} \hat{\alpha} + \frac{L_D}{L} \hat{\beta} + \frac{K_D}{K} \gamma \right) Y_c \tag{5}$$

The equations (4) and (5) implicitly assume that the total productivity is equal in each region. To take into account the regional productivity differences, we calculate the productivity corrected value added of part *c* created in region R as follows:

$$\hat{Y}_{c,R} = \frac{MFP_R\left(\frac{C_R}{C}\hat{\alpha} + \frac{L_R}{L}\hat{\beta} + \frac{K_R}{K}\gamma\right)}{\sum MFP_R\left(\frac{C_R}{C}\hat{\alpha} + \frac{L_R}{L}\hat{\beta} + \frac{K_R}{K}\gamma\right)} Y_c \qquad R \in (D, E, N, A, O) \qquad (6)$$

,where MFP_R is multi-factor productivity in region *R*.

Thus, for instance the domestically created value added is calculated as follows:

$$\hat{Y}_{c,D} = \frac{MFP_D\left(\frac{C_D}{C}\hat{\alpha} + \frac{L_D}{L}\hat{\beta} + \frac{K_D}{K}\gamma\right)}{\sum MFP_R\left(\frac{C_R}{C}\hat{\alpha} + \frac{L_R}{L}\hat{\beta} + \frac{K_R}{K}\gamma\right)} Y_c \qquad R \in (D, E, N, A, O) \qquad (7)$$

Operationalizsation of production factors

If component-level factors and factor shares are unavailable, we use firm-level information on the location of different factors. Firm-level data is based on the annual reports and web-sites of each vendor. We have operationalizsed variables as follows:

C = Non-current assets or long-lived assets depending on which one has been reported in 2007.

L = Number of employees (in 2007).

K = R&D expenditure. We are unable to calculate R&D-stock for each region thus we have used R&D expenditure in 2007.

In some cases, the reported regional breakdown of some factor is imperfect. In those cases, we have read carefully the entire annual report and also searched necessary information from the Internet in order to approximate roughly the regional breakdown. For instance, National Semiconductor (U.S company) reports the regional breakdown of long-lived assets (annual report, p. 104) and employees (annual report, p. 12), but do not report exact geographical breakdown of their R&D expenditure. However, in p.21 the company reports that their principal research facilities are located in Santa Clara (California, the U.S), and that they also operate small design facilities in 13 different locations in the U.S and 11 different locations outside the United States. Out of those 11 overseas R&D units, roughly half are located in Asia and half in EU-15 area. Based on these facts and the number of facilities per region, we estimate that roughly 70% of R&D is done in the U.S. and we divide the rest of 30% fifty-fifty for Europe (15%) and Asia (15%).

Operationalizsation of multi-factor productivity (*MFP)*:

We have used value added based *MFP* figures of the Electrical and optical equipment and Post and Telecommunicationss industries reported by Inklaar & Timmer (2008). This data is downloadable at www.ggdc.net/databases/levels.htm. Based on this database, the regional MFP's used in our estimations are as follows:

$MFP_D = 1.24$ (Finland)

$MFP_E = 0.81$ (the average of EU-15 countries excluding Finland)

$MFP_N = 1$ (United States)

$MFP_A = 0.52$ (the average of Japan, China, South-Korea and Taiwan). The *MFP*s of China, South-Korea and Taiwan are based on Motohashi (2008) using Japan as a reference country (Japan=1.00).

$MFP_O = 0.37$ (the average of Australia, Czech Republic, Hungary, Slovenia)

APPENDIX 3

Robustness test 1:

To test to what extent our results depend on our assumptions related to the value added created by material suppliers' vendors, we recalculate the geographical breakdown of value added by changing these assumptions. One could argue that Asia's role in these upstream activities is bigger than we assumed in our basic calculations. Moreover, Australia, Russia and Africa are important raw material providers, and in this sense our basic assumptions potentially under-estimate the role of these regions. Due to these two reasons, we raise the share of Asia to 50% and Other countries (including, e.g., Australia, Russia and Africa) to 30% of the value added created by vendors of vendors, and respectively lower the share of EU-27 to 10% and the North-America to 10%. Then we re-calculate all potential combinations related to the final assembly location and the country of final sales. The results of this re-calculation show that our basic results hold. On average, overall 52% of the total value added is captured in EU-27, 14% in North America, 22% in Asia and 12% in the rest of the world.