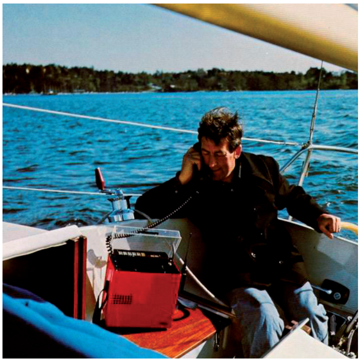
VINNOVA ANALYSIS
VA 2008:06



Effects of research on Swedish Mobile Telephone Developments: THE GSM STORY

Summary

ERIK ARNOLD, BARBARA GOOD, HENRIK SEGERPALM

Title: The GSM Story - Effects of Research on Swedish Mobile Telephone Developments Summary
Author: Erik Arnold, Barbara Good & Henrik Segerpalm – Technopolis Group
Series: VINNOVA Analysis VA 2008:06
ISBN: 978-91-85959-17-4
ISSN: 1651-355X
Published: May 2008
Publisher: VINNOVA – Swedish Governmental Agency for Innovation Systems/Verket för Innovationssystem
VINNOVA Case No: 2007-02594

About VINNOVA

VINNOVA, Swedish Governmental Agency for Innovation Systems,

Research and Innovation for Sustainable Growth.

VINNOVA´s mission is to *promote sustainable growth*
by funding *needs-driven research*
and developing *effective innovation systems*.

Through its activities in this field, VINNOVA aims to make a significant contribution to Sweden´s development into a leading centre of economic growth.

The VINNOVA Analysis series includes publications of studies, analyses, official reports and evaluations that have been produced or commissioned by VINNOVA´s Strategy Development Division.

VINNOVA´s publications are published at www.VINNOVA.se
I VINNOVAs publikationsserier redovisar bland andra forskare, utredare och analytiker sina projekt. Publiceringen innebär inte att VINNOVA tar ställning till framförda åsikter, slutsatser och resultat. Undantag är publikationsserien VINNOVA Policy som återger VINNOVAs synpunkter och ställningstaganden.
VINNOVAs publikationer finns att beställa, läsa och ladda ner via www.VINNOVA.se. Tryckta utgåvor av VINNOVA Analys, Forum och Rapport säljs via Fritzes, www.fritzes.se, tel 08-690 91 90, fax 08-690 91 91 eller order.fritzes@nj.se

Effects of Research on Swedish Mobile Telephone Developments:

The GSM Story

Summary

Erik Arnold, Barbara Good, Henrik Segerpalm
Technopolis Group

VINNOVA's foreword

Ericsson's development of mobile telephony is one of Sweden's outstanding industrial successes of recent years in terms of turnover, employment and exports. This impact study focuses on the role of Swedish government research funding in the development of technology for mobile telephony, especially GSM, and the subsequent Swedish success.

The study shows that a number of factors were important. These included the dialogue between the supplier Ericsson and the customer Swedish Telecom and their mutual support in the international standardisation process. Another factor was the technological capabilities and market strength already built up under the Nordic cooperation that created the NMT system. Under the research leadership of Sven-Olof Öhrvik and then Jan Uddenfeldt, the Ericsson subsidiary SRA (later Ericsson Radio) undertook key technical developments. At the time, this was a company with few resources, compared with today's Ericsson. Until its transformation into a state-owned limited company in 1992/93, Swedish Telecom had a 'sectoral responsibility' for research in the area, and its Radio Labo-ratory, managed by Östen Mäkitalo, played an vital role.

R&D financed by VINNOVA's predecessors STU and NUTEK in the period 1975 – 1998 was of major importance in two respects

- Building up research capacity at universities and institutes of technology that produced professors, PhDs and MSc engineers – individuals well prepared for a career within industry, whom Ericsson and Telia could employ during the huge expansion of business of the 1990s
- Financing research that made technical breakthroughs possible

The European R&D programmes RACE and ACTS were important to the developments that took place in the later part of the 1990s.

A team from the Technopolis Group, comprising Erik Arnold (project leader), Barbara Good and Henrik Segerpalm, conducted the study. They were supported by an eminent reference group including: prof em Lars Zetterberg, KTH; Östen Mäkitalo and Conny Björkvall, formerly Swedish Telecom/TeliaSonera; Jan Uddenfeldt and Jan-Erik Stjernvall, Ericsson; Lennart Alfredsson, formerly SRA and Ericsson, and Bengt-Göran Bengtner, formerly Swedish Telecom and Ericsson. The group also included Sven-Ingmar Ragnarsson, Eva Westberg and Anders Hedin from VINNOVA. Torbjörn Winqvist acted as VINNOVA's project leader.

The impact studies that VINNOVA performs, at the Swedish government's request, are particularly valuable in describing the longer-term effects of R&D funding. We wish to thank all those who have contributed to the study, both those already mentioned and the many others who have shared their experiences in interviews and in other ways.

VINNOVA in April 2008

Per Eriksson
Director General

Göran Marklund
Director
Head of Strategy Development Division

TABLE OF CONTENTS

Summary

The Swedish government requires that VINNOVA should produce 'impact studies' to illustrate the social and economic effects of its funding, or the funding of its predecessor agencies. This is one of a series of reports that is beginning to shed light on the long-term benefits of state-funded, use-oriented R&D. Unlike conventional evaluations, the VINNOVA effect studies focus on the longer-term relationships between research and socioeconomic development. They therefore have a scope that can in cases go back for 40 years, in order to explore these long-term effects of the heritage of innovation policy learning and practice represented by VINNOVA today.

This report looks at the connection between research funded by VINNOVA's predecessors STU and NUTEK and the extraordinary transformation of the Swedish telecommunications industry (notably Ericsson) over the past 30 years or so. We focus especially on the period when the GSM digital mobile telephone system was being discussed, standardised and designed.

Many relevant records have disappeared or are difficult to access, so the study involved a lot of oral history and archaeology. We interviewed some 70 of the people involved, sent a short questionnaire to people who took PhDs relevant to mobile telecommunications in Sweden during the last 30 years and built up a 'human capital' database to map what has happened to them since then as well as reading a great deal of secondary literature. Our intention was to find out the extent to which university research funded by STU/NUTEK influenced the development of GSM and the great Swedish industrial success in the area.

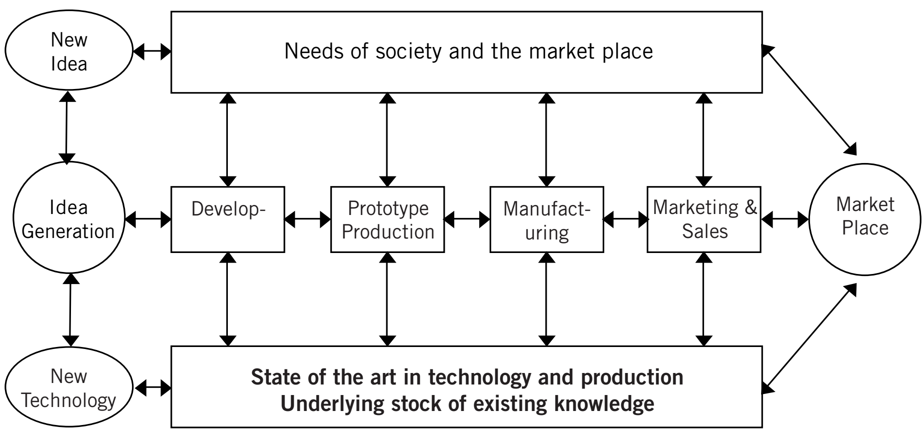
The links between public R&D support in Sweden, during and immediately after the period when the GSM digital mobile telephone standard was being developed help explain the huge success of Ericsson and the Swedish mobile telephony industry in the period since then. These links were non-linear: research did not develop new knowledge that industry then gratefully implemented. Rather, the interaction of industrial and research agendas focused university research and education on problems whose solution in theory and in industrial development enabled Ericsson's huge success and all the employment, trade and income benefits that has brought to Sweden. While the study examines one particular history, it suggests some general lessons about how to design public R&D policy and how and why companies and other producing organisations can fruitfully interact with the knowledge infrastructure.

Swedish Policy and Theory About the Effects of Research

Two simple theories have dominated past discussion about the relationship between research and innovation. One is the 'linear model' that treats research as producing **information** that then prompts innovators to innovate. The other is the 'human capital' model that says the value of research is that it trains people with generic skills, whom industry can then socialise into doing practical things. Ever since the Malm Commission reported in 1942, much Swedish research policy has leant towards the human capital perspective.

The modern research literature on the links between research and innovation suggests that neither the linear nor the human capital model is adequate. There are many links and loops within innovation processes and these processes do not start at any particular 'place' in the innovation system. Modern models of the links between knowledge generation and innovation are always complex. Exhibit 1 shows one of the most influential of these models.

Exhibit 1 Modern 'Coupling' Model of Innovation



Source: Mowery, D.C. and Rosenberg, N., 'The Influence of Market Demand upon Innovation: A Critical Review of Some Recent Empirical Studies', *Research Policy*, April 1978

Only a small proportion of innovations involve R&D. Firms tend to innovate using their existing knowledge but successful innovators often build relationships with the research sector in order to extend that knowledge. Companies are driven to do R&D when they discover problems that need to be solved so that they can innovate. Therefore, a key to successful technological innovation is for firms to possess 'absorptive capacity': that is, the ability both to define technological problems and to recognise and exploit solutions. This complexity demands that we take an innovation systems perspective when we try to explain and promote successful innovation.

When problems need to be solved, not just any old knowledge will do. Devices are needed that focus research attention on the problems. Successful innovating firms and partner universities develop positive feedback loops, becoming attuned to each other's evolving needs. Incentives for the universities to participate include the fact that the companies can provide interesting problems (or identify which out of many possible problems are likely to lead to a line of research), justify expansion not only of the research effort but also of education, and influence a use-oriented R&D funder to provide money. Creating or encouraging 'focusing devices' is thus one of the ways an innovation agency can add value in the innovation system.

Digital Mobile Telephony

The basic principles of cellular mobile telephony have been known since the 1940s but the technology needed in order to implement them is much more recent. Nordic countries were leading in the first (analogue) generation of mobile telephones (launched in the 1980s) because of joint action by the Nordic telecommunications authorities and their important role in developing as well as specifying the needed technology. Swedish Telecom (Televerket, later Telia) was especially important in this process.

Exhibit 2 Mobile Telephony Generations

Generation	1G	2G	3G-	3G (2)	3G+ (4G)
System Examples	NMT AMPS TACS	GSM, PDC, D-AMPS, cdma One, DECT, PHS	GPRS EDGE	WCDMA TDCDMA MCCDMA	HIPERLAN/2 WLAN WATM
Maximum user data rate		9.6 kbps	384 kbps	2 Mbps	20 Mbpd
Dominant service	Analogue speech	Digital speech	Internet Data Speech	Multimedia Internet IP-telehony	High speed data using IP
Introduced	1982	1992	2000	2002	3G: 2002 (4G: 2012?)

Source: Sven-Olof Öhrvik

The second (digital) generation of mobile telephones (launched in the 1990s) became possible in part because of the development of microelectronics that enabled digital signal processing. Swedish Telecom played a leading role in initiating and seeing through the standardisation process via the Groupe Spécial Mobile, which gives its name to the GSM mobile telephone system. The European GSM standard has become globally dominant in second-generation mobile telephony. Sweden had an important influence over key parts of the GSM standard, notably the way radio signals are coded and transmitted between handsets and base stations. This helped maintain Sweden's leadership in both producing and using mobile telephone systems. However, Swedish Telecom was not alone on the Swedish side in this standardisation process. The researchers in Ericsson's radio companies were extremely active in proposing and testing possible parts of the standard and they involved a number of university researchers in developing some of the knowledge needed.

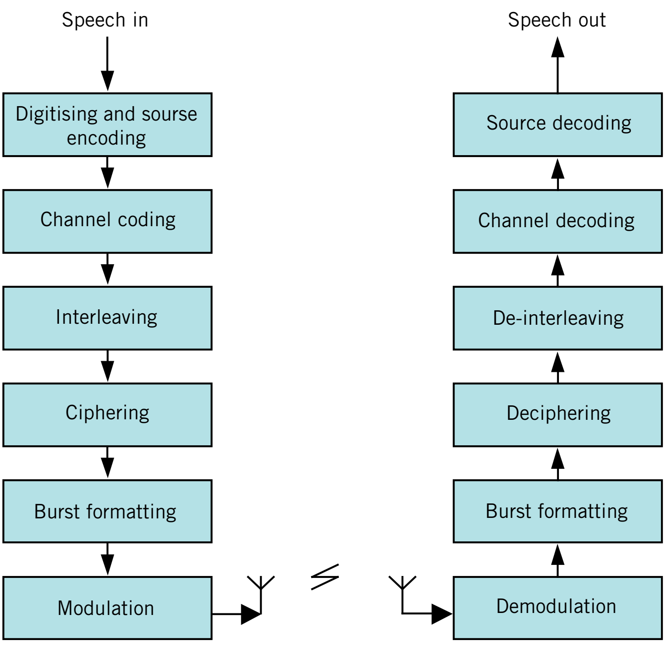
The NMT system had already solved important architectural questions about how to design an international mobile phone network so the designers of the second generation had a pretty clear idea what they were trying to make. However, designing the digital radio link between mobile telephones and the base stations that let them access the telephone network posed a number of challenges.

1 How to convert and code speech into digital form, using as little bandwidth as possible while maintaining a level of speech quality that the consumer would accept
2 How to code multiple conversations (and other forms of communication such as fax) into a single channel while getting very fast communication between the mobile phone and the base station
3 How to protect the coded signal from fading and noise in the radio channel
4 How to modulate the resulting digital signal over radio waves while maintaining high bit rates
5 A particular problem was how to cope with 'inter-symbol interference' caused by radio waves bouncing off buildings and other hard objects so that they arrive out of phase at the receiver
6 How to implement the solutions to these problems in electronic components

All these problems had to be solved within important constraints. They had to be economical with bandwidth; they had to be small so that it was possible to make hand-held mobile phones; their implementation had to be affordable, in order to allow the market to develop; and they had to use very little power, so that available battery technology could be used while giving handsets a long enough battery life to be practical. In fact, while the solutions to these problems tended to use principles from existing theory it took a lot of research and development to go from theoretical principles to solutions that could be used in practice.

The solutions for coding multiple conversations and protecting the codes from disturbances during radio transmission tend to overlap. (Exhibit 3) gives an overview of the steps involved in going from speech to a coded radio signal and back again.

Exhibit 3 Sequence of Operations from Speech to Radio Waves and Back



Currently, the third generation of mobile telephony is partly implemented but continues to evolve rapidly to higher bandwidths and a wider range of services, as does the whole field of digital wireless communications.

Telecommunications is one of many industries that rely heavily on standards. The national telecommunications authorities, their international network the International Telecommunications Union and regional standardisation bodies such as the CEPT European standards body for posts and telecommunications – another club of the national monopolies – formerly controlled these standards. But liberalisation of telecommunications markets has removed their control and industry increasingly sets *de facto* standards, as has long been normal in the computer industry. Now, equipment manufacturers are much more involved and the battles over standards and markets is taking place mostly at the global level.

The second generation of mobile telephony was significant in that it was planned to accompany the start of competition, especially in Europe, so while the telecommunications authorities remained important industry also had considerable voice. This changes the needed role of the state in helping apply knowledge to support national actors and consumers. Swedish Telecom therefore played a dominant role in representing Sweden in the standardisation process for NMT, while it in practice tended to share that role with Ericsson in second-generation standardisation. In the third and fourth generation, Swedish Telecom (now Telia) has very little voice in a debate that is to a greater extent among global companies. With liberalisation, too, Swedish Telecom (Telia) can no longer afford to do R&D that largely produces public goods for Sweden, so like other former state monopolies it has drastically downsized its R&D capabilities and become a standards-taker rather than a standards-maker. Correspondingly, it is no longer a development partner for Ericsson and to the extent that it makes sense in the national interest to foster linkages with the research and higher education system this responsibility now falls wholly on national research funders like VINNOVA[1].

Through its partnership with Swedish Telecom, the Ericsson group achieved a strong market position in NMT systems and built further strength in international markets for first generation mobile telephone systems on this basis. Competitors hoped that the change in technology to second-generation systems would weaken Ericsson's position and increase their own opportunities. The most controversial part of the GSM standard was therefore the radio access link, where the bigger technological changes needed to be made. Ericsson and Swedish Telecom began research on these questions very early, linking with researchers at four Swedish universities and at SINTEF, and were able to have a strong influence over the standard. In particular this meant that it was decided that GSM would use a narrowband TDMA[2] multiple access technique – which was especially suitable for the large cell sizes used in Nordic systems (owing to the low population density) but that could also be used for smaller cells in densely populated areas. As a result, Swedish Telecom did not have to find many new base station locations but could share with its existing NMT stations. And it meant that key parts of the GSM standard reflected areas where Ericsson was technologically strong. This helped Ericsson maintain its leading position.

The Role of VINNOVA's Predecessor Agencies

VINNOVA's predecessors STU and NUTEK were closely involved in funding research that contributed to creating the second generation – a funding tradition that carries on in VINNOVA.

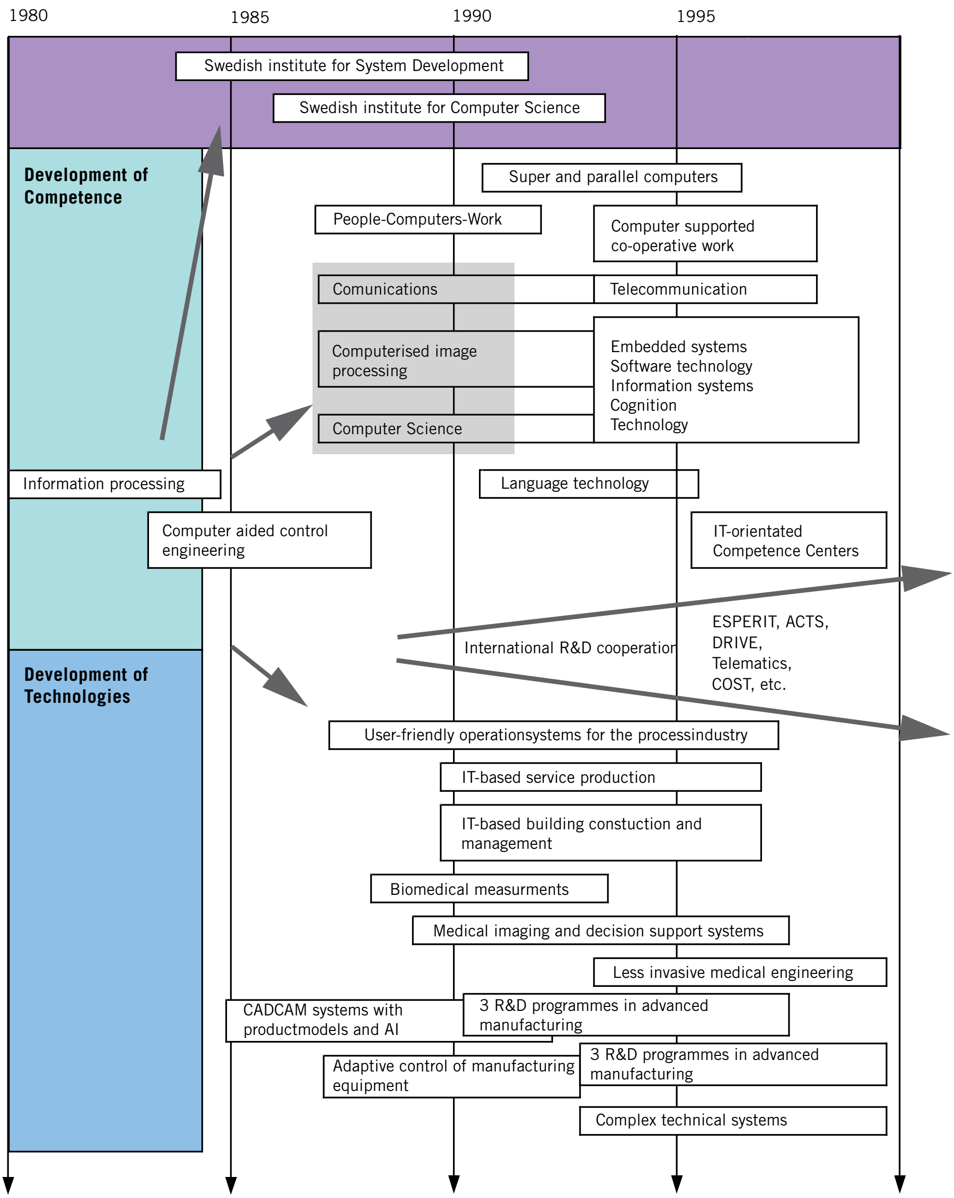
1 Formally, 'sector responsibility' for research and research capacity in telecommunications passed from Swedish Telecom to NUTEK in 1993, when Swedish Telecom was corporatised

2 Time Division Multiplexed Access

In its first few years, STU was rather reactive, receiving research proposals and using scientific councils to choose which to fund. This research-council-like behaviour meant that what STU funded represented the aggregate of what applicants – especially the universities – demanded. The General Audit Office complained about this lack of strategy and a special STU Commission was appointed to look into how the agency was running. As a result of that Commission's work, in the late 1970s, STU decided to change its role and to become a more active change agent. To do this, it devised a programming process (continued by NUTEK and VINNOVA) that took account of the best scientific and industrial opinions about needs and then used stakeholders to support it in funding collections of projects aimed at common goals. This meant that it could selectively use R&D grants to build capacity in the universities to focus attention on new areas and enable the research and education system to tackle industrially and socially important subjects. In other words, it could now build 'focusing devices'.

STU/NUTEK supported the development and growth of Information and Communications Technology (ICT) capacity in universities and industry from the late 1970s through a mixture of programming and bottom-up funding of projects. It developed a large suite of ICT-related programmes through the 1980s, which have since been continued and evolved by NUTEK and VINNOVA. It was also key in orchestrating the national IT programme, spanning microelectronics (NMP) and information technology (IT). These represented an important increment of state funding over and above normal budgets and involved substantial industrial as well as academic research and were key triggers for the scaling up of ICT research and education in Sweden that was needed in order to meet the challenges of the electronics revolution.

Exhibit 4 STU/NUTEK IT Programmes 1980-2000



Source Torbjörn Winqvist, VINNOVA. Grey area represents IT3

Funding Research on Digital Communications

In 1977, just before STU started using programming, small units in Ericsson (SRA, later ERA) and Swedish Telecom (the Radio Lab) started an informal 'radio club' together with a handful of academics interested in the problems of digital radio communications. They identified the areas in which they believed research was needed in order to make digital radio communications viable and ran research, development, test-bed and evaluation projects alongside the university research. SRA always had its own internal R&D agenda and used the university research as a way to explore options, acquire new understanding of how to do things and develop and recruit high-level technical manpower. The activities of the radio club meant that both the research and the industrial communities were already well advanced and knowledgeable when GSM standardisation formally started, in 1982, putting Sweden in a much better position than many other countries to influence and exploit the GSM standard as it emerged.

During the time of the radio club, STU was a willing discussant and project-funding partner. STU staff often attended meetings of the radio club and were involved in discussions of the technology road maps for second generation mobile telephony that were being used in industry. It had the technical and industrial competence to assess research proposals in terms not only of quality but also of relevance to the new digital communications trajectory. In effect, it made many bets on fairly small projects. It was even prepared to take risks by funding people who had good colleagues and whose work was industrially relevant but who themselves had little track record.

Exhibit 5 STU Grants for Digital Mobile Related Research, 1978-86

	CTH	KTH	LTH	LiTH	Total
1978			50,000		**50,000**
1979		488,750	798,000	1,820,000	**3,106,750**
1980		729,910	2,485,000	307,808	**3,522,718**
1981		771,105	696,500	1,337,900	**2,805,505**
1982	605,980	1,111,292	283,560	2,354,340	**4,355,172**
1983		620,122	712,000	900,720	**2,232,842**
1984	1,050,200	1,542,000	1,024,300	1,150,100	**4,766,600**
1985	425,900	1,109,000	1,895,000	2,509,300	**5,939,200**
1986	706,000	1,198,300	2,480,000	741,000	**5,125,300**
Totals	**2,788,080**	**7,570,479**	**10,424,360**	**11,121,168**	**31,904,087**

Source Analysis of STU/NUTEK's 'Peanuts' administrative database

Over time, it became more and more obvious that the area of digital mobile communications would be industrially very important. In discussion with Ericsson and Swedish Telecom, STU launched the Digital Communications programme in 1987, which doubled the amount it was investing per year in the field and started a process of increasing the research, PhD production and engineering education effort for digital communications – just in time to help Ericsson with the huge scaling-up it needed to undertake of its research and development activities between 1988 and 1998, in order to take advantage of its strong potential in GSM and other second generation digital systems. NUTEK continued the programme when it was formed in 1991 and there has been a succession of programmes in the area run by NUTEK and now VINNOVA, with the latest one launched in 2008.

In the late 1980s, too, Swedish Telecom and Ericsson began to become strongly involved in the EU RACE programme and other international R&D activities such as COST, in order to position themselves for the third generation of developments. From the 1990s, Ericsson was essentially fighting the Swedish corner of research and standardisation debates alone, without the technical support (and even leadership) it had previously enjoyed from Swedish Telecom. The corporatisation of Swedish Telecom to become Telia put an end to its role as a major R&D performer and technology developer.

The Research

This study looks in quite some detail at which researchers did what research during the period of the radio club and GSM standardisation, and has confirmed that the links between their work and that of the industry were achieved through coordination and parallel working.

Perhaps the central fact about the role played by the Swedish research community in GSM standardisation and in underpinning Ericsson's huge economic success in mobile telecommunications is that it was not random and it was not a result of researcher-directed R&D. Rather, it was carefully orchestrated by a small number of people in support of industrial needs. The key characters were Sven-Olof Öhrvik, Jan Uddenfeldt and Östen Mäkitalo – all graduates of KTH, the latter two having been supervised by Lars Zetterberg, who may in many senses be regarded as the 'father' of Digital Signal Processing (DSP) in Sweden. The first two worked for the Ericsson group (Uddenfeldt succeeded Öhrvik as head of ERA's research department in 1985), while Mäkitalo headed Swedish Telecom's Radio Laboratory. All three were involved in the development of radio **systems**. As a result, they were in the unusual position not only of having responsibility for generating new designs but being able to see the knowledge needs across the breadth of the systems they were trying to create. Because they could see the knowledge bottlenecks, they were not only able to supply university researchers with a stream of problems but also able to say which were the important ones for industrial development.

The radio club was centred on the universities of Linköping, Lund and Chalmers. After some time, KTH also became involved. It involved a mixture of professors and doctorands. The key issues they tackled were speech coding, channel coding, modulation, radio propagation, equalisation and VLSI components (especially for digital signal processing) – precisely addressing the problems that needed to be resolved in order to make the transition from analogue to digital radio access.

Lund was especially important, in that it had maintained an interest in radio during a period when other universities were dropping radio work in favour of various digital technologies. (A consequence of this was a shortage of radio engineers in Sweden during the 1980s and 1990s.) Researchers from Lund involved in the radio club tackled a wide range of questions including radio propagation, modulation, coding and electronic component design for mobile communications. At least two of the doctorands were shipped off to America to learn and bring back design and process technologies from US universities. The link with Ericsson became especially close as SRA's head of research moved to take a chair in Lund in 1985, after a period as an adjunct professor. Ericsson built its main factory for handsets opposite the university.

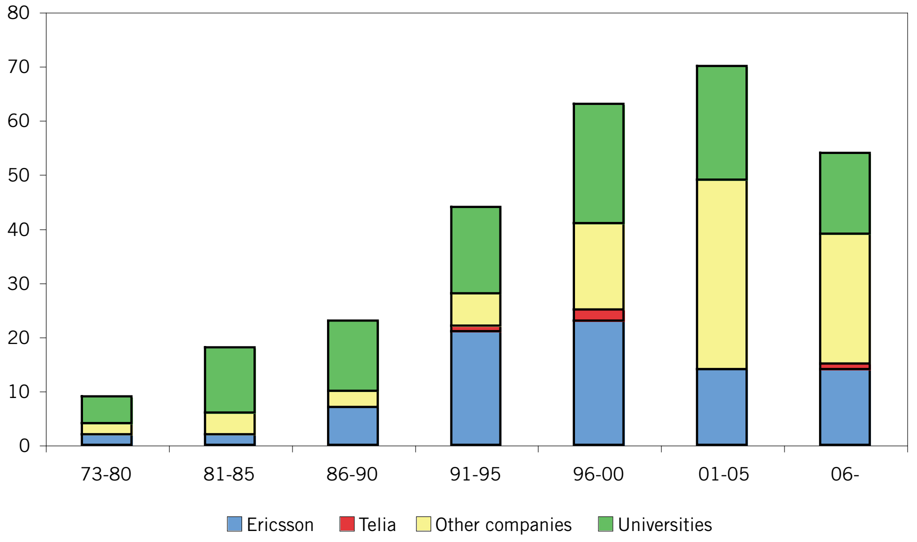
Linköping worked on channel coding, error-correction and equalisation while Chalmers focused more on speech coding/decoding and modulation. KTH's focus was on digital signal processing, the technology through which much of the work on radio access was in practice implemented.

Ericsson ran its own research projects in parallel with the university work and there was a great deal of interaction amongst the various researchers in connection with the construction of various engineering test beds that, together with the standardisation process and the needs of later development engineering, focused the common effort. Swedish Telecom hosted a series of test beds where industrial and academic researchers worked together to simulate first radio access and later larger parts of second-generation systems.

Development of Human Capital

We have looked at what happened to the researchers involved, tracking three or more generations of doctorands from the time of the radio club, the Digital Communications programme and subsequently. Our track of PhDs 'produced' by the research groups established by the members of the radio club and others involved in the Digital Communications programme has identified 315 people as doing PhDs (281) or licentiates (34) in or close to the fields considered by the radio club. This work shows a pattern of new PhDs tending to stay in the universities in the first half of the 1980s, followed by a growth in the proportion of new PhDs going into industry. Our analysis effectively shows a process of building research and teaching capacity in the universities followed – especially from the time of the STU/NUTEK Digital Communications programme – by large-scale industrial take-up of research manpower. The pattern of growth continued through the 1990s and into this decade. During the set-back years for Ericsson at the start of the 2000s, a bigger proportion of PhDs went to other industrial employers but on our analysis Ericsson's recruitment of PhDs related to digital mobile communications appears to have started to recover.

Exhibit 6 Mobile-Relevant PhD Production, 1973-2007 By Current or Last Location



Source: Technopolis survey, interviews and Internet searches

These increases were of course accompanied by the entry of additional universities and the formation of more research groups. At the time of the radio club there were perhaps five relevant groups spread across four universities. Today there are twenty groups in seven universities. In the areas relevant to digital communications, the Swedish university system today has at least ten times the research and education capacity present when the radio club began and a corresponding increase in education at engineer level. The massive increase in output was crucial for supplying the skills the industry needed. In the 10 years up to 1998, the number of PhDs in SRA/ERA's research department multiplied tenfold from about 5 to 50 and the number of MSc-level engineers grew from about 50 to 500 in the same period. Total R&D staff in Ericsson Radio also grew by factor of ten between 1988 and 1998 (from 1,000 to 10,000 people). The fact that the research staff were a fairly constant 5% of total R&D staff reflects Ericsson's commitment to maintaining a high level of technological and absorptive capacity, including continuing dialogue and cooperation with universities – increasingly on a worldwide basis.

The human capital developed in connection with digital mobile communications is of course only one part of a much bigger picture of scaling up the research and higher education system to meet the opportunities and needs of a time where ICT is an important part of the economy. STU, NUTEK and VINNOVA have contributed to this development through a series of programmes that helped the university system to build new capacities.

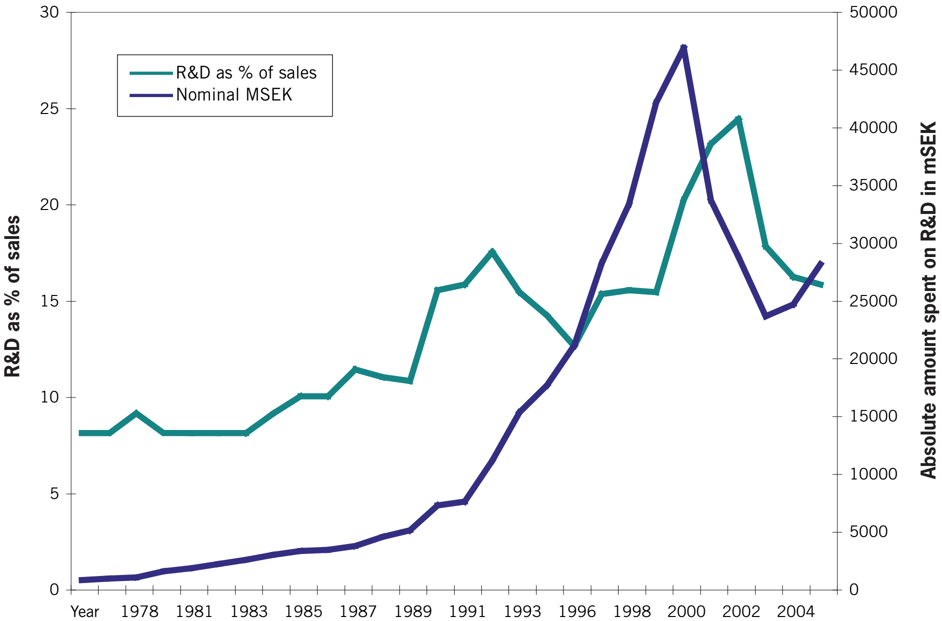
Ericsson

The story of Ericsson's positioning in the GSM market told here (and confirmed by our interviewees in Ericsson and elsewhere) is that Ericsson was able to capture a strong position by being first with an integrated and credible systems solution.

Ericsson is by far the largest organisation in Sweden concerned with mobile telecommunications. The story of mobile telephony in Sweden is also a story about the transformation of a rather staid, slow-moving company working for state monopolists, often on innovations more or less created by the customers and moving at their often-glacial pace, to becoming a significant, nimble, technologically proactive global player in telecommunications equipment, with all the positive things that implies for employment and wealth in Sweden.

SRA's history of working with military radio meant that it had the chance to work with new technologies like transistors and digital radio ahead of those who served only civilian markets, because the military were able to pay the big bills that come with the most advanced technologies. It was a tiny island capable of real research and its successes in early mobile telecommunications meant that, even if it was felt to be peripheral to the main company mission, top management tolerated it. Through the 'focusing device' of the radio club and later programmes like Digital Communications, it cooperated with the university sector so that it maintained leading-edge internal R&D capabilities and influenced standards, establishing itself as probably the world's most credible deliverer of complete mobile telephony systems by the early 1990s. In order to do so, it co-opted Ericsson's main fixed telecommunications product, the AXE exchange, driving growth in Ericsson's core business. The radio cuckoo did not push the other chicks out of the nest – it fed them. The transformation of the core business from fixed to mobile telecommunications meant that Ericsson became much more R&D-intensive, spending 16% of turnover on R&D in 2006, compared with 8% in 1976, something that was only possible because of the large increase in engineering and doctoral education during the relevant period.

Exhibit 7 Ericsson R&D, 1976-2006



Source: Ericsson Annual Reports

Both the two driving technologies exploited by Ericsson owed a lot to public research funding: the radio side predominantly through STU/NUTEK; the AXE switching side through Swedish Telecom; and both were possible because the National Microelectronics Programme supported key process and design technologies.

While SRA's cooperation with Swedish Telecom during the 1980s focused on GSM, the company was building a research-based skill set that enabled it to tackle all three major second generation standards and quickly to move to being a global, not a European, player in mobile telephony.

From Ericsson's perspective, a key to making use of the research community's interest in technologies relevant to mobile telephony was to be asking the community questions based on its own internal development. Often the university research projects were highly theoretical while Ericsson's projects aimed to be simpler, producing robust solutions that used the minimum of electric power and that could eventually be implemented in components or software. There was a constant dialogue with the universities, which ensured that Ericsson understood its technological options. Especially in the period up to the mid-1980s, Ericsson did not recruit all that many PhDs from the universities: it was better that they stayed in place and taught new generations of engineers and PhDs, to supply Ericsson's growing appetite for personnel. However, many doctorands from the radio club and the subsequent programme now have key positions in Ericsson top management, reflecting the flow of new capabilities through the research department into product development then product responsibility.

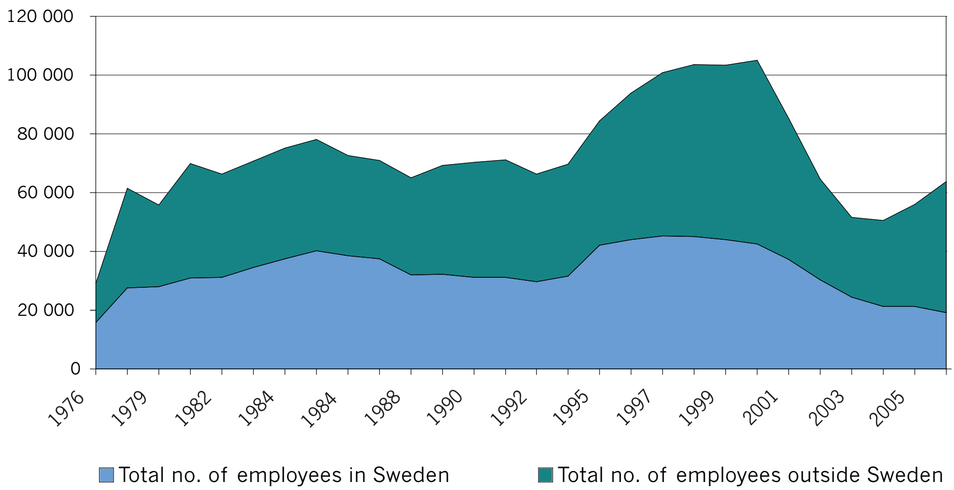
Effects

Our conclusion in this study is that public research funding, especially that of STU/NUTEK, had a major effect in enabling Sweden's success in mobile telephony, bringing benefits to Ericsson, the university system, Swedish Telecom and many other parts of Swedish society. There is always a problem of **attribution** in making such a claim, however, because while the research funding appears to have been necessary it was by no means alone sufficient to cause the success: many other factors were also important.

Ericsson

The Ericsson group is the most obvious winner from the research funding. Ericsson's economic success in the latter 1980s and the 1990s was massive, as a result of its transformation from a fixed-lines to a mobile telecommunications company. Employment peaked at over 100,000 before the crash of the early 2000s, from which Ericsson has now begun to recover. Ericsson has generated many billions of kronor of economic activity, which benefits the Swedish economy and makes the major contribution to Sweden's large trade surplus in telecommunications.

Exhibit 8 Ericsson Employment: Overall and in Sweden, 1976-2006



Source: Ericsson Annual Reports

The fact that Ericsson took the initial lead in the GSM market was crucial. Being second would not have delayed Ericsson's growth in mobile telephony – it would largely have prevented it. Technically, that success depended in part on Ericsson's radio access skills, in part on its components capabilities (including the ability to threaten to make its own unless suppliers were willing to offer acceptable prices and deliveries) and in part on the AXE switch developed in collaboration with Swedish Telecom and implemented using technology acquired through the NMP. All three aspects benefited substantially from state research funding.

Ericsson faced the prospect of acute skill shortages in the 1980s – both in specific radio-related areas and in ICT more generally. Its ability to exploit its strong position in GSM depended upon the increasing output of PhDs and MSc resulting both from STU/NUTEK's Digital Communications programme and from the bigger national effort to expand IT research, training and education that STU had helped trigger in the early 1980s. Given the supply of manpower, Ericsson then had the capacity (just!) to build on its TDMA/GSM capabilities and quickly to develop systems for two other important standards. Its leading global position in 2G systems then provided the basis for strength in 3G.

Without STU/NUTEK's role as change agent in the research and innovation system, Sweden would not have been able to take advantage of the opportunities afforded by mobile telephony and in the best case Ericsson would have had to pursue its expansion to a greater extent outside Sweden.

Universities

The public research funding led to a body of knowledge and publications but its more important effect in the university sector was to launch a trajectory of growth in the capacity to do research and teaching in subjects relevant to digital mobile telephony.

The universities were both enablers of Ericsson's success through their research and education activities and also beneficiaries of it – not only through research and teaching to meet the growing needs of the mobile telephony industry but also because there is positive feedback from Ericsson in particular in the form of funding, collaborative projects and a continuing flow of information about emerging problems. Odd as it may sound, a supply of problems is one of the most valuable things one can have in such disciplines, not only because they underpin day to day research and education but because they can define new research trajectories. And just as in industry, in academia timely knowledge of what the important problems are is often key to competitive success.

STU/NUTEK funding therefore triggered a very considerable expansion of doctoral education and a very large supply of highly qualified people into both industry and academia. This is a structural shift: the institutional structure is in place in the universities that should assure the continuation of this supply.

Swedish Telecom

While Swedish Telecom can reasonably be credited with creating one of the world's most advanced mobile telephone markets in the NMT era and was a crucial enabler of Ericsson's success through cooperation over AXE and in the GSM standardisation process, it has perhaps itself not benefited as much as other sectors from the expansion of ICT research and education – either at the general level or in the specific case of digital mobile communications. The use of narrowband TDMA in the GSM specification meant that Swedish Telecom could use its existing NMT base station sites to deploy GSM rather than having to set up new ones to create the smaller cell sizes implied by other access methods, and this has produced a significant saving compared with alternatives. However, the change in Swedish Telecom's role with corporatisation and liberalisation means that it no longer makes so much use of highly qualified R&D manpower, so the effects of the research funding on human capital have been less important for Swedish Telecom (now Telia) than for others, though it has undoubtedly contributed to ensuring the company does not suffer from shortages in the technical manpower it needs to run the business.

Sweden

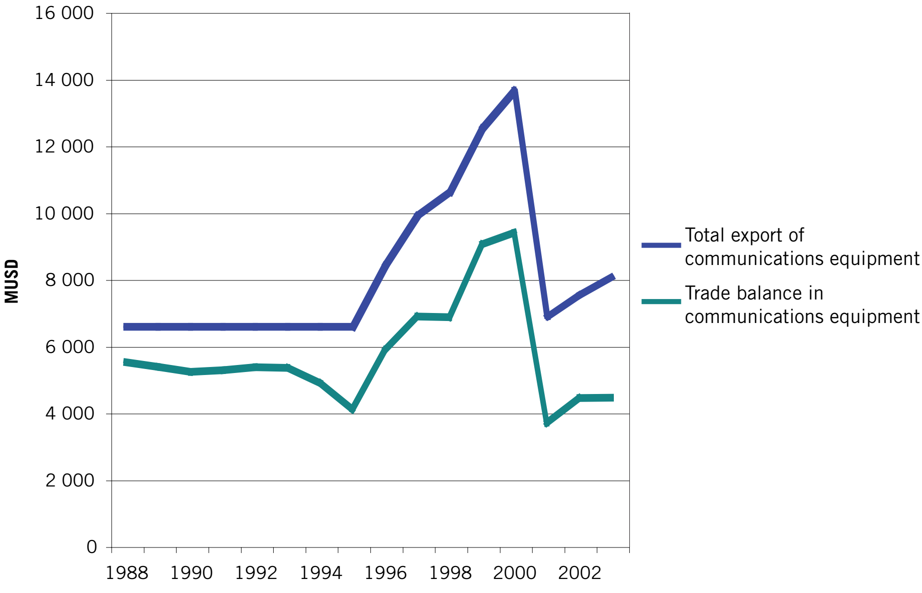
The Swedish taxpayer more broadly has benefited significantly from the Swedish success in mobile telephony to which public research funding has contributed.

One of the most important aspects from the national perspective is the creation of a large cadre of people in industry and in the knowledge infrastructure who understand and work with digital communications. Conventionally, we try to count the benefits of an intervention such as a research programme in the industrial world by looking at its effects on individual companies. In this study, we have focused heavily on the Ericsson group. But to a considerable extent, the community of people who work with a technology persists more strongly than individual companies. Thus, when Ericsson downsized in the early 2000s, many people set up their own businesses in related areas of telecommunications and electronics.

The research programmes studied here also triggered significant changes in the university system, making it much more adapted to the needs of the 21st Century than it had previously been. This is also an important effect for the taxpayer.

This study has focused heavily on Ericsson. We have not explored the effects on the company's suppliers but – while Ericsson products necessarily have a high import content in the form of semiconductors – the economic multiplier resulting from Ericsson's increased activity will also be considerable. However, even without considering this, it is clear that there are huge benefits for Ericsson in Sweden – and that these result in the employment of large numbers of Swedish workers and the payments of large amounts of Swedish taxes as well as a healthy contribution to Sweden's balance of trade.

Exhibit 9 Swedish Exports and Trade Surplus in Telecommunications Equipment, 1988-2003



Lessons

The implications of STU/NUTEK funding for employment and wealth creation need to be considered with care. The fact that there are so many necessary but not sufficient conditions drives us towards the innovation systems view of the world that underpinned the formation of VINNOVA. This implies that a large number of sub-systems of the national innovation system need to function well and to be well interconnected if the system as a whole is to perform. In this view, we cannot attribute success to any one factor, but we can rather clearly say that if a component of the national innovation system fails then overall performance will fall – potentially catastrophically. This study demonstrates in some detail how the links between publicly funded R&D and Ericsson's capabilities and success operated. Without the publicly funded R&D it is clear that there would not have been the same success.

The research literature suggests that there are at least eight channels through which research tends to be linked to innovation processes

1 Increase in the stock of useful knowledge
2 Supply of skilled graduates and researchers
3 Creation of new scientific instrumentation and methodologies
4 Development of networks and stimulation of social interaction
5 Enhancement of problem-solving capacity
6 Creation of new firms
7 Provision of social knowledge
8 Shared access to unique facilities

The focus of this study was such that we did not look for instances of company start-ups (though it is highly likely there were some). But we observed all the other channels in use.

The GSM case clearly illustrates that the role of R&D in this innovation was as something that had to be done on the way to achieving an innovation goal. Digital mobile telephony did not happen because someone did some research and realised they could build a GSM handset with the results. It happened because organisations understood that digital technology was the key to mass mobile telephony and set about solving the problems in the way of achieving this innovation. Some of those problems were solved via R&D. Others needed re-regulation. Yet others required changes in distribution channels and the invention of new pricing strategies. Early attempts did not all succeed in going digital – had it been technically possible at the time, NMT would have been an all-digital standard, but that had to wait for various component technologies to mature.

One question we tried to resolve in this study was whether there were 'critical events': points at which it is possible to see a particular research result passing into practice. There turn out to be almost no such events in this area. It seems that it is competence and understanding of how to do things, not individual facts, that move between university and industrial researchers – at least in this case. Operating in parallel and sometimes in cooperation with internal SRA and Swedish Telecom projects, the research community effectively explored technological options and transferred not solutions but an understanding of how to get to solutions.

The study illustrates the importance of absorptive capacity in industry as a way to create the initial capabilities needed to move into disruptive technologies, the opportunities available through long-term relationships between researchers in companies and universities and the opportunities to use problems – defined, for example, in relation to a standard or a test bed or a road map – to focus university research on industrially relevant questions.

SRA's proactivity is an extremely important part of this story that was only made possible by its small core of research-capable people. The radio club was a focusing device: an arena where research ideas and results were exchanged. SRA's proactivity went well beyond the radio club, however. It decided to locate its plant only next to universities of technology – not only so that it could conveniently pick up new recruits as they graduated but also so that it could influence the direction of research and education in directions that helped meet the company's needs.

The creation and movement of human capital turns out to be extremely important in the mobile telephony story. Without the scaling up of the research and higher education effort Ericsson would not have been able to exploit the opportunities in digital communications. But not any old human capital would do: for some things the company needed people with particular skills; for others, it could benefit from the more general ramping up of IT research and education. Just as a focusing device was needed to excite researchers about research directions relevant to the problems in developing GSM, so that same device pointed the way towards the need for PhDs and MSc courses.

Overall, the study confirms the importance of the role of an intelligent, research-funding change agency, supporting use-oriented research and helping construct 'focusing devices' that link needs to research agendas. The history shows that STU/NUTEK's internal skills and competences were very important in enabling the mobile telephony success. The interaction between SRA, the radio club and STU was fruitful partly because STU had the technical competence to be a discussion partner. As a result, STU received access to companies' and academics' views about technological needs, likely trajectories and road maps and to an understanding of industrial development that could not have been understood by a purely administrative apparatus. The fact that project officers themselves took funding decisions enabled them to negotiate and participate even in the process of project development, where necessary, and they were therefore welcome at the table when the radio club met.

The STU/NUTEK people involved were not 'bureaucrats' but were often former researchers from related fields. They generally had no need to go and consult a committee of experts in order to understand and decide about a proposal. STU/NUTEK was willing to let the project officers make a number of project-level bets – normally rather modest in size – in the expectation that some would pay off and the certain knowledge that many would not. In the case of the radio club, this meant that some of the doctorands and junior researchers were able to get funding despite their complete lack of an academic track record because STU/NUTEK was able to put faith in them and their context. Avoiding the normal funding Catch-22 for new fields seems to have been a useful contribution to launching the research field quickly.

At the time when the radio club started, STU was able to deal with the radio club through response-mode project funding and to monitor developments in the field. Once it became clear that digital communications would be important and that there would be a high demand for people with R&D skills in that area, STU/NUTEK was able to launch a specific R&D programme – one of whose explicit aims was to scale up the operation. The ability to move from a responsive/monitoring mode to a programming mode was key to developing the field and to creating the supply of mobile-relevant relevant manpower needed to underpin Ericsson's expansion. STU/NUTEK's analytical capacity and close contact with industrial needs also underpinned its role in promoting the idea of a national IT programme and orchestrating it across multiple agencies and their ministries. This 'top down' strategic capacity, together with its lower-level and partly more responsive actions such as in digital communications, appears to have been a winning combination.

Another important lesson to draw from the mobile telephony history is the role of Nordic cooperation in the early stages. Since EU accession, there has been increased scepticism about the value of the Nordic cooperation but – while there are of course a number of special circumstances that are hard to repeat – this is a clear demonstration of the value of building a Nordic platform from which to take on the world – an idea that has recently reappeared in Nordforsk's virtual Nordic Centres of Excellence and the new NordicNets.

Policy Implications

This study illustrates the complexity of the relationship between innovation and research and the role of many conditions that are necessary for innovation but none of which is sufficient. In the absence of sufficient conditions, a crucial policy implication must be that interventions must have a systemic perspective, taking account of bottlenecks and opportunities as these arise. Simplistic interventions based solely in ideas like the linear model or the naïve human capital model are unhelpful, however attractive their simplicity may be. This understanding underlies the EU and OECD discussion today about 'policy mix'.

The mobile telephony history points to the need to think about policy mix on two levels. One is the mix between the research-council style of funding, dominated by concerns about quality and track record, on the one hand and on the other more explicitly use-oriented research funding, with its concern to establish links with innovation processes in order to generate social and economic benefits. Both styles are needed in a system that is intended both to do fundamental research and to support economic and social development (the 'third task' of the universities). Hence, the research community needs incentives to do both these things.

At the level of the innovation agency, the history suggests a need to balance response-mode project-by-project funding and programmed funds. The point of the response-mode funding is not only to react to isolated good ideas but also to act as a kind of 'search engine' to look for needs and opportunities. To do these things requires substantial technological competence; bureaucracy and the mechanical application of standardised assessment criteria cannot accomplish it. It also requires a portfolio approach because no matter how good the intelligence applied, innovation projects are highly prone to failure. Neither a research council nor an administratively driven agency could have reacted to, fostered and eventually scaled up the radio club in the way STU/NUTEK's internal intelligence let it.

The success in mobile telephony naturally prompts the question: How can we do more of this?

- The point of departure of our story was SRA's internal technological capability and its 'absorptive capacity'. Instruments like 'industry doctorands' that encourage the injection of research skills into companies are also important, in order to raise the level of absorptive capacity and to form an 'advance guard' of research capability. Once such people are inside the firm, they start to suck in others
- 'Focusing mechanisms' are crucial, and drive not only research but also education. If a new area of knowledge becomes important then there will be a need for knowledge-bearers at both first degree and PhD levels. In a university system with research-based teaching, first-degree education will tend to follow directions established at PhD level
- Large-scale changes may nonetheless require national coordination across multiple agencies and ministries, as was the case in the national IT programmes
- In VINNOVA's world, there are projects and there are programmes. VINNOVA could usefully explore the opportunities for encouraging more intermediate-level focusing devices like the radio club
- STU/NUTEK, like VINNOVA, had the twin instruments of bottom-up and programmed funding at its disposal. This meant that it had the flexibility in the early years to respond to developments while in the later period to formalise the activity into a programme that was able to scale it up and meet national needs. This required planning and budgeting mechanisms that were tuned to the industrial wavelength – that could receive and amplify signals from groups of industrialists and researchers and use these to trigger programmes. An

innovation agency needs to combine such responsiveness with its own centralised analytic intelligence. It needs a radio, it should be switched on and someone should be listening!

- Weinberger suggested that STU's key success factors were: money; a credible vision of technological developments; and the ability to judge quality.[3] Such an organisation should clearly be interdisciplinary in character. A significant part of the capability must be technological in character and that means the personnel should have a high proportion of technologists
- The money was also important. We have looked at a case where STU/NUTEK's bet succeeded, but there were others that did not. One of the strengths of project funding is that it lets the agency search for opportunities while containing the cost of failure. In uncertain circumstances, it is better to bet a couple of projects than a whole programme. (The motto should be 'Lose small; win big'.) Crucially, the portfolio of projects has to be large enough to let the winners win through and the culture has to understand failure as part of the search process, not as poor performance
- Weinberger's description of STU as a 'network entrepreneur' is a good one and a good description of STU/NUTEK's activities more generally. The observation of STU's second director-general, Bertil Agdur, that STU should not be an administrative apparatus but a **change agent** goes to the heart of the role of an innovation agency
- Despite the policy focus on SMEs in recent years, the example of digital mobile telephony shows both that large companies can need support in establishing focusing devices and the massive rewards that can result from success when large firms are involved

A number of policy implications for industry also emerge from this study.

- The story of SRA/ERA as a small, almost semi-official island of high technological capability within a large company with a focus on other things illustrates the importance of absorptive capacity. Without an initial few research-capable people, it would have been much harder to see the developing importance of digital radio communications, to identify the technological bottlenecks and to encourage researchers to work on these. Maintaining a core of research capability was important, at least in this case
- The interactions with the universities were selective, focused on current and future development issues and backed up by internal projects. The capacity to

3 Hans Weinberger, *Nätverksentreprenören*, Stockholm: KTH, 1997

interact in this way, as well as to do internal research, needs to be maintained across long periods, in order to tackle successive product and technology cycles. It is not a one-time requirement but a permanent one that should drive the kind of long-term relationships that Ericsson has developed with Lund, KTH, Berkeley and other universities

- These links are needed not only in order to obtain and absorb knowledge from outside but also in order to maintain the supply of skilled and specialised R&D labour needed by influencing the activities in the university system. SRA's idea of setting up shop outside the gates of the universities of technology was in this sense absolutely the right thing to do
- Another success factor for Ericsson has been the ability clearly to distinguish research from development and to organise these differently. The outputs of research are knowledge and uncertainty-reduction, not products and processes
- The examples of the radio club and the various test beds that were key to the GSM story suggests that these kinds of arenas should actively be developed by industry where it needs to focus research interest on matters of importance to it. In the absence of development pairs these days, such arenas need to be comparatively open. The risks of openness are contained, however, by the fact that the ultimate benefits for the company are learning how to do things (and what things not to do) and manpower; generating product or process secrets is unlikely

VINNOVA´s publications

May 2008
See www.vinnova.se for more information

VINNOVA Analysis

VA 2008:

01 VINNOVAs Focus on Impact – A Joint Approach for Impact Logic Assessment, Monitoring, Evaluation and Impact Analysis

02 Svenskt deltagande i EU:s sjätte ramprogram för forskning och teknisk utveckling. *Only available as PDF*

03 Nanotechnology in Sweden – an Innovation System Approach to an Emerging Area. *For Swedish version see VA 2007:01*

04 The GSM Story – Effects of Research on Swedish Mobile Telephone Developments. *For brief version in Swedish or English see VA 2008:07 or VA 2008:06*

05 Effektanalys av ”offentlig såddfinansiering” 1994 – 2004

06 Summary – The GSM Story – Effects of Research on Swedish Mobile Telephone Developments. *Brief version of VA 2008:04, for brief version in Swedeish see VA 2008:07.*

07 Sammanfattning – The GSM Story. *Brief version of VA 2008:04, for brief version in English see VA 2008:06*

VA 2007:

01 Nanoteknikens innovationssystem. *For English version see VA 2008:03*

02 Användningsdriven utveckling av IT i arbetslivet – Effektvärdering av tjugo års forskning och utveckling kring arbetslivets användning av IT. *For brief version in Swedish and English see VA 2007:03 and VA 2007:13*

03 Sammanfattning – Användningsdriven utveckling av IT i arbetslivet – Effektvärdering av tjugo års forskning och utveckling kring arbetslivets användning av IT. *Brief version of VA 2007:02, for brief version in English see VA 2007:13*

04 National and regional cluster profiles – Companies in biotechnology, pharmaceuticals and medical technology in Sweden 2004. *Only available as PDF. For Swedish version see VA 2005:02*

05 Nationella och regionala klusterprofiler – Företag inom fordonsindustrin i Sverige 2006

06 Behovsmotiverade forskningsprogram i sektoriella innovationssystem. *For English version see VA 2007:15*

07 Effekter av den svenske trafikksikker-hetsforskningen 1971-2004. *For brief version in Swedish and English see VA 2007:08 and VA 2007:09*

08 Sammanfattning – Effekter av den svenska trafiksäkerhetsforskningen 1971-2004. *Brief version of VA 2007:07, for brief version in English see VA 2007:09*

09 Summary – Effects of Swedish traffic safety research 1971-2004. *Brief version of VA 2007:10, for brief version in Swedish see VA 2007:07.*

10 Effects of Swedish traffic safety research 1971-2004. *For brief version in Swedish and English see VA 2007:08 and VA 2007:09*

11 Svenskt deltagande i sjätte ramprogrammet. *Only available as PDF*

12 The role of Industrial Research Institutes in the National Innovation System

13 Summary – User-driven development of IT in working life – Evaluating the effect of research and development on the use of information technology in working life. *Brief version of VA 2007:02, for brief version in Swedish see VA 2007:03*

14 VINNOVAs fokus på effekter – En samlad ansats för effektlogikprövning, uppföljning, utvärdering och effektanalys

15 Needs-driven R&D programmes in sectorial innovation systems. *For Swedish version see VA 2007:06*

16 Biotechnology, pharmaceuticals and medical technology in Sweden 2007 – Cluster profiles

VA 2006:

01 End of an era? Governance of Swedish innovation policy. *For Swedish version see VA 2005:07*

02 Forskning och utveckling vid små och medelstora företag. *Only available as PDF*

03 Innovationsinriktad samverkan. *Only available as PDF*

04 Teknikbaserat nyföretagande i Sverige 1990 - 2003. *Only available as PDF*

05 Offentligt stöd till universitetens samverkansuppgift – en internationell kartläggning. *Only available as PDF*

06 Inkubatorer i Sverige – analys av indikatordimensioner och nyttoefektivitet. *Only available as PDF*

VINNOVA Forum

VFI 2007:

01 Universitetet i kunskapsekonomin *(Innovation policy in Focus)*

02 Tillväxtgenvägen – affärsinnovation i svenska tjänsteföretag *(Innovation policy in Focus)*

VINNOVA Information

VI 2008:

01 Upptäck det innovativa Sverige.

02 Forskningsprogrammet Framtidens personresor – Projektbeskrivningar

03 Passenger Transport in the Future – Project Descriptions

04 Vehicle ICT – Project Descriptions

05 Forska&Väx – Program som främjar forskning, utveckling och innovation hos små och medelstora företag

06 Årsredovisning 2007

VI 2007:

02 MERA-programmet – Projektkatalog. *For English version see VI 2007:03*

03 The MERA-program – Projects. *For Swedish version see VI 2007:02*

04 DYNAMO 2 – Startkonferens & Projektbeskrivningar

05 IT för sjukvård i hemmet – Projektkatalog

06 VINNVÄXT – Ett program som sätter fart på Sverige! *For English version see VI 2007:09*

07 Årsredovisning 2006. *Only available as PDF*

08 Het forskning och innovationskraft – VINNOVA 2006. *For English version see VI 2007:10*

09 VINNVÄXT – A programme to get Sweden moving! *For Swedish version see VI 2007:06*

10 Red-hot research and innovation power – VINNOVA 2006. *For Swedish version see VI 2007:08*

12 Projektkatalog – Genusperspektiv på innovationssystem och jämställdhet. Forsknings- & utvecklingsprojekt för hållbar tillväxt

14 VINN Excellence Center

16 SWEDISH RESEARCH FOR GROWTH – A VINNOVA Magazine

17 VINNOVAs satsningar för små och medelstora företag

18 EU-projekt: Mer värt än pengar

19 EU-forskning ger nya möjligheter – EU-projekt Arbete & Resultat

VINNOVA Policy

VP 2008:

01 Forskning och innovation för hållbar tillväxt – VINNOVAs förslag till forsknings- & innovationsstrategi 2009-2012

02 Offentlig upphandling som drivkraft för innovation och förnyelse. *Only available as PDF. For English version see VP 2007:03*

VP 2007:

01 Innovativa små och medelstora företag – Sveriges framtid. SMF-strategi från VINNOVA

02 Forskningsstrategi för miljöteknik – Redovisning av regeringsuppdrag till Formas och VINNOVA. *Only available as PDF*

03 Public procurement as a driver for innovation and change. *For Swedish version see VP 2008:02*

VINNOVA Report

VR 2008:

01 Mot bättre vetande – nya vägar till kunskap på arbetsplatsen

02 Managing Open Innovation – Present Findings and Future Directions

03 Framtiden är öppen! Om problem och möjligheter med öppen källkod och öppet innehåll

04 First Evaluation of the Institute Excellence Centres Programme

05 Utvärdering av det Nationella Flygtekniska forskningsprogrammet – NFFP. Evaluation of the Swedish National Aeronautics Research Programme – NFFP

06 Utvärdering av Vehicle – Information and Communication Technology programmet – V-ICT

07 Kartläggning av ett halvt sekels jämställdhetsinsatser i Sverige

08 Politiken, offentlig verksamhet – en av tre parter i samverkan

09 Forsknings- och innovationspolitiken i USA – Näringslivets fem roller

VR 2007:

01 Design of Functional Units for Products by a Total Cost Accounting Approach

02 Structural Funds as instrument to promote Innovation – Theories and practices. *Only available as PDF*

03 Avancerade kollektivtrafiksystem utomlands – mellanformer mellan buss och spårväg. Tillämpningsförutsättningar i Sverige. *Only available as PDF*

04 VINNVÄXTs avtryck i svenska regioner – Slutrapport. *For English version see VR 2007:06*

05 Utvärdering VINNVINN Initiativet

06 Effects of VINNVÄXT in Swedish regions – Final report. *For Swedish version see VR 2007:04*

07 Industry report on exhaust particle measurement – a work within the EMIR1 project. *Only available as PDF*

08 Swedish innovation journalism fellowships – en utvärdering. *Only available as PDF*

09 Rörlighet för ett dynamiskt arbetsliv – Lärdomar från Dynamoprogrammet

10 Miljöbilar och biodrivmedel – Hur påverkas Sverige av EUs direktiv?

11 Evaluation report by the VINNVÄXT International Review Team

12 DYNAMO Arbetsgivarringar för ökad rörlighet – En slututvärdering av projekt om arbetsgivarringar inom DYNAMO-programmet

13 Är svenskt management konkurrenskraftigt? – Trettio ledare om svenskt management, dess konkurrenskraft och framtida utveckling – resultat från en intervjuundersökning

14 First Evaluation of the VINNOVA VINN Excellence Centres NGIL, HELIX, SAMOT and ECO^2 together with the STEM Competence centre CICERO

15 Vart tog dom vägen? – Uppföljning av forskare och forskning vid nedläggningen av Arbetslivsinstitutet

16 Bättre cyklar – en analys av äldre cyklisters behov och önskemål. *For English version see VR 2007:17*

17 Better cycles- an analysis of the needs and requirements of older cyclists. *For Swedish version see VR 2007:16*

Production: VINNOVA´s Communication Division
Layout: West studios **Cover:** Anders Gunér
Printed by: Åtta.45, www.atta45.se
May 2008

Effects of research on Swedish Mobile Telephone Developments: THE GSM STORY – Summary

Ericsson's development of mobile telephony is one of Sweden's outstanding industrial successes of recent years in terms of turnover, employment and exports. This impact study focuses on the role of Swedish government research funding in the development of technology for mobile telephony, especially GSM, and the subsequent Swedish success.

The study shows that a number of factors were important. These included the dialogue between the supplier Ericsson and the customer Swedish Telecom and their mutual support in the international standardisation process. Another factor was the technological capabilities and market strength already built up under the Nordic cooperation that created the NMT system.

VINNOVA´s mission is to promote sustainable growth
by funding needs-driven research
and developing effective innovation systems

VERKET FÖR INNOVATIONSSYSTEM – SWEDISH GOVERNMENTAL AGENCY FOR INNOVATION SYSTEMS

VINNOVA, SE-101 58 Stockholm, Sweden Besök/Office: Mäster Samuelsgatan 56
Tel: +46 (0)8 473 3000 Fax: +46 (0)8 473 3005
VINNOVA@VINNOVA.se www.VINNOVA.se