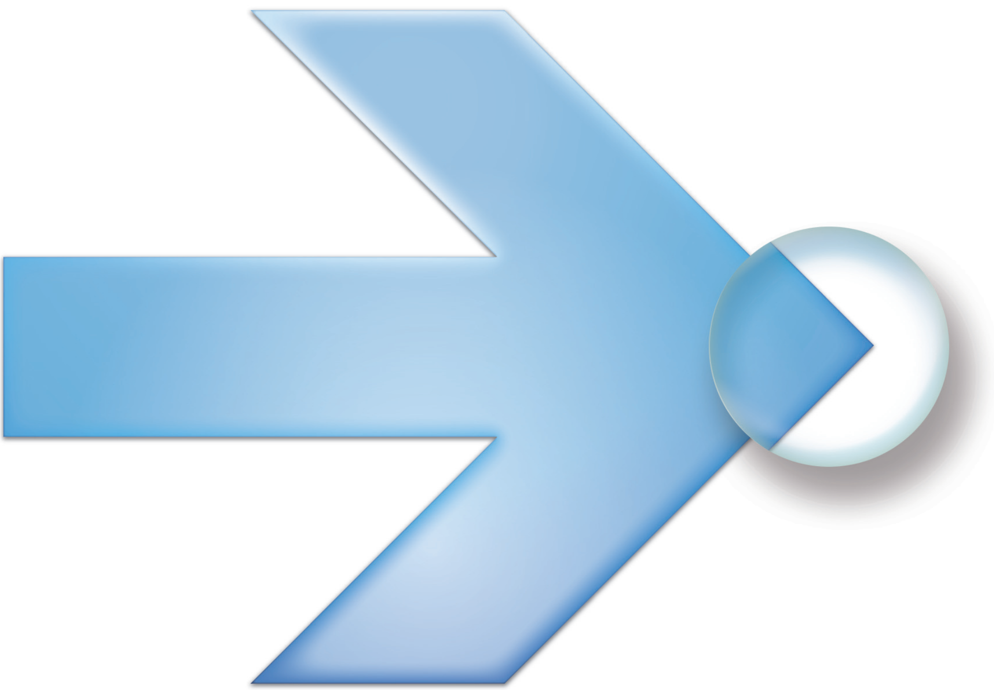
VINNOVA ANALYSIS
VA 2010:07

SUMMARY IMPACT ANALYSIS

OF SUPPORT FOR STRATEGIC DEVELOPMENT AREAS IN THE SWEDISH MANUFACTURING INDUSTRY



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- contribute making Sweden a leading research nation in which research of high scientific quality is conducted.
- promote sustainable growth and increased employment by acting to increase competitiveness and the emergence and expansion of successful companies.
- support research and development work of the highest quality in areas such as engineering, transport, communications and working life in order to promote renewal and sustainable growth.
- stimulate Swedish participation in European and international R&D collaboration and in the exchange of experience in the field of innovation.

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SUMMARY - Impact Analysis of support for strategic development areas in the Swedish manufacturing industry

by

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Foreword

In order to understand and to be able to learn from the long term impact following from VINNOVA's efforts, impact analyses are performed. In these, the impacts from more than just single programmes are analyzed.

This summary primarily deals with the impacts of five programmes which VINNOVA and its forerunner Nutek ran (1996–2009) in the area of product manufacture. The R&D-efforts that are studied can be considered important for the participating companies' choices and potential to carry out projects for development within product manufacture. The complete study (in Swedish) can be found in the VINNOVA report ”Effektanalys av stöd till strategiska utvecklingsområden för svensk tillverkningsindustri” (VINNOVA Analys, VA 2010: 05).

The programmes have brought about impact of substantial value. Among them we find important ones like increased competitiveness among participating companies, following from new business opportunities and new business. In that context, a development of the companies' methods and patterns of collaboration has emerged, sometimes radically, not seldom towards open innovation.

The developments of technology and method have mainly taken place within already established, larger corporations. However, the programmes have also generated technology dissemination or spillover, both within and between sectors as well as to small and medium sized enterprises. The efforts have not helped to start many new companies, though.

Impact analyses performed by VINNOVA, and commissioned by the Swedish government, are very important since they offer a description and an understanding of the overall and long term impacts following from investments in research, innovation and sustainable growth. We like to thank all people who have directly contributed, or shared from their experience, and thus made possible the accomplishment of this study.

VINNOVA, July 2010

Charlotte Brogren	*Göran Marklund*
Director General	Director
	Head of Operational Development Division

Contents

Introduction

This impact analysis deals primarily with the impacts of five programmes which VINNOVA and its forerunner Nutek ran (1996–2009) in the area of product manufacture. It comprises five full-scale substudies in the areas of Functional Sales (FS), Free-Form Fabrication (FFF) and a section of the area Industrial IT (IT). The five programmes had a total public budget of just over SEK 700 million which, with few exceptions, funded research and development (R&D) at research institutes and universities (Univ). The public investments were matched by roughly equal investments from participating companies, usually in the form of in-kind initiatives.

The principal reason for the impact analysis is to contribute to an understanding of the way in which initiatives of the kind represented by the programmes lead to impacts within industry, and what these impacts are.

The established impacts can only partially be deemed a direct consequence of the five programmes, as there has been a parallel finding of a significant number of other R&D programmes supporting the same R&D milieus as these five. The other primary financiers are VINNOVA (through other programmes) the Swedish Foundation for Strategic Research (SSF) and the European Commission. This impact analysis therefore proceeds from a systemic view, taking into account the overall impacts of all financiers in context of relevant R&D efforts.

Overall impacts

This section gives an account of the overall, long-term impacts which it has so far been possible to verify for each area. For details of the five programmes and three substudies as well as a detailed review of the results appearing in this study, please refer to subsequent parts of this summary and the main report.

Functional Sales substudy

Two very robust R&D milieus at Linköping University (LiU) and Luleå University of Technology (LTU) have grown strong within the area of functional Sales/functional products. This is largely due to grants from Nutek and VINNOVA. The R&D milieus have concentrated their industrial collaborations on their particular handful of companies which made an active contribution to R&D projects. These companies have implemented the R&D results to a significant degree and are using them variously in their own business activities. In a number of cases, the R&D results of these projects have been fully commercialised, in others they are part of in-house, ongoing development and in a few cases they have entirely abandoned notions of functional sales, partly due to changed market conditions.

We have several examples from companies who, by implementing R&D results and utilising their own enhanced competence, achieved a very marked increase in their competitiveness. The collaborative patterns which emerged between the R&D implementers and industry are considered valuable and both parties have largely gone on collaborating with those they previously worked with, albeit with a healthy reworking of their groupings. A number of corporate representatives point out that the R&D implementers have got better at understanding corporate needs, which guarantees a more effective partnership.

A clear majority of project managers at universities and institutes state that further corporate collaboration arose as a result of participation in VINNOVA programmes. The corporate partnerships indicate a spread of knowledge to companies which did not participate in the original projects as well as a spread of knowledge to industries which had not previously been involved, such as medical technology, railway transportation and pulp and paper.

A considerable number of research-trained people have been examined within the area and the majority of these are now working in industry. This would facilitate the dissemination of functional sales and, through the increased absorption capacity this entails, generally improved opportunities for companies to take on board external R&D results.

Free-Form Fabrication substudy

During the latter part of the 1990s, a number of small companies grew up which offered services within the area of free-form fabrication. To be more specific, they offered a model manufacturing service. In most cases, these service agencies were run by people from the network that grew out of the activities of the industrial research institute (IVF), funded by Nutek.

Amongst their customers, this led to improved product development process and new applications which, in turn, quite likely led to new commercial opportunities and new business. However, FFF is now regarded as a technology integrated into design, structure and prototype manufacture; one “tool” amongst many. “Nowadays, nobody thinks of it as a separate technology”, was the way one person put it. For many of the companies, the actual technology is not (or has not been) their core activity. Thus, it is difficult to trace and evaluate the significance of this particular technology to these companies.

Of those companies which currently have FFF as the core of their operation, the majority manufacture end-use products or prototypes, whilst many are just agents or distributors of FFF products. It mostly involves small or medium-sized enterprises (SMEs), sometimes with only two or three employees. The largest company employs around 50. Of these 20-plus SMEs (around one third of which are agents or distributors without their own production), most were involved in the network activities run by IVF during the 1990s.

The FFF technology has now been implemented and established within the Swedish engineering industry, although it has not lived up to the aspirations of the pioneering stage of being able to produce components with good mechanical properties. The technology is used for prototype manufacture throughout the entire engineering industry, and it is within or between companies where the development has continued. However, we have not been able to substantiate the fact that this development began with Nutek’s efforts in the 1990s, even though it seems reasonable to suppose that IVF’s initiatives must at least have facilitated the spread of the technology. There again, within medical applications there have been more results from VINNOVA’s efforts, but these are more recent.

Industrial IT substudy

The area of Industrial IT comprises the two sub-areas of Geometry Assurance[1] and IT Process[2]. Within the former sub-area, it can be confirmed that continuous support for successful application-orientated R&D milieus (under a range of programmes planned and implemented in partnership with industry) has led to considerable positive impacts for companies. In the initial stage, this has been the case for the automotive industry and there are signs that there may also be tangible impacts on other industries in later stages. In this area, the continuous support has also led to ongoing development in the research and the construction of a strong and sustainable R&D and innovation milieu with based at Chalmers University of Technology (CTH), Fraunhofer-Chalmers Research Centre for Industrial Mathematics (FCC) and Swerea IVF. This milieu has continued to produce R&D of good international standing whilst simultaneously providing industry with research-trained personnel and engineering graduates who have increased companies' competence and strengthened their competitiveness within strategic areas.

Within IT Process, the structural impacts are of a different kind and therefore less clear since the R&D support is spread across a large number of R&D implementers. However, even here there are examples of R&D implementers maintaining competitiveness or having opportunities to build it up.

Concerning industry, there are clear instances that the R&D activities being supported have led to a fairly comprehensive industrial use of simulation software in design, construction, pre-production engineering etc., which has increased product quality and significantly shortened the time for manufacturing new products. At the same time, the partnership between R&D implementers and companies has led to a development of corporate competence and working methods to facilitate significant – and in some cases substantial – reductions in production costs.

A small consultancy company has also appeared as a kind of impact of the R&D support and is an important link in the development chain. In a subsequent stage, there are also instances of the simulation technology concerned having spread within the automotive industry and having started to spread to other industries, and this leading to the development of subcontractor competence and competitiveness. Swerea IVF has played an important role in this latter development which is clearest within IT Process.

[1] Geometry Assurance relates to all activities aimed at minimising the impacts of geometrical variation in the finished product.
[2] The IT-supported production processes of shaping, machining, heat treatment and assembly.

Where it concerns research, we have confirmed that R&D support has led to a number of research students being employed primarily at CTH. Since more than 30 of these are now working with R&D in industry, they jointly (with engineering graduates who have trained in these areas) comprise a strategic competence resource. At the same time, a critical mass has built up particularly in connection with CTH and the R&D support in these areas has laid the foundations for the Wingquist Laboratory which has received comprehensive ongoing support from both VINNOVA and SSF, as well as under the government's effort in the area of strategic research.

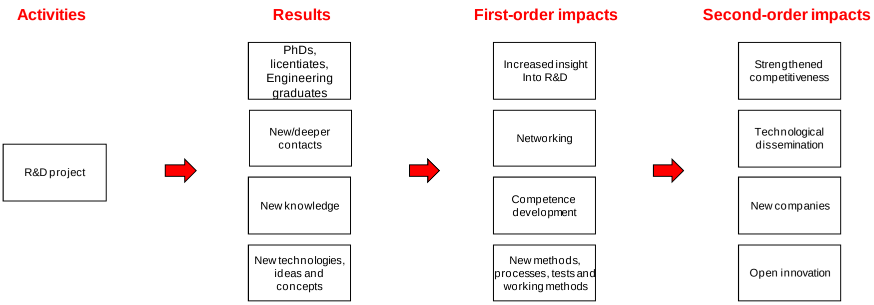
Correspondingly but on a smaller scale, the School of Industrial Production at the Royal Institute of Technology (KTH) has been strengthened as a result of its participation in the five programmes and has received extensive support under the government's strategic research effort. A new R&D milieu with LTU as one of the partners is also experiencing growth as a result of this support, whilst the School of Engineering at Jönköping University (JTH) has been able to put itself forward on a national level.

The applied research has been further developed and has given rise to the development of industry-relevant software. However, a result has been that a more "industry-relevant" working method has spread amongst the contributing R&D implementers. As a result of this, their competence has also become more attractive to industry. Swerea IVF has maintained its role by developing its own services and has been able to develop its role as a bridge builder and disseminator Of technology in relation to SMEs. The R&D support has also led to a targeting of research at new fields of application, the appearance of follow-up projects, a certain renewal of undergraduate studies and to contributing R&D milieus becoming more internationally competitive.

Summary of overall impacts

The demonstrated overall and long-term (second-order) impacts within the three substudies in this study can be compared under a number of headings, with the deliberate aim of providing a concise overview. These impacts may constitute the basis of a coherent impact logic (see Figure 1) which demonstrates how the correlation appears when it is "working as it should" – something which impact analyses have not always been found to do.

Figure 1. Summary of impact logic for the five programmes.



Strongly competitive

In the best cases, initiatives such as those in the studied programmes lead to companies being strongly competitive. The capacity to solve industrial problems quickly, efficiently and innovatively carries a competitive advantage in the form of reduced development and manufacturing costs and through the opportunity to offer a product or service with functionality that a competitor cannot provide. This also opens up new commercial opportunities and new business and can thus ultimately form the basis of industrial renewal and robust companies.

Dissemination of technology

We have seen several examples of technology being disseminated between industries and from larger companies to SMEs. In most cases we have studied, the drivers of technological development have been automotive and occasionally aviation companies. However in many cases, through the agency of the R&D implementers, there are good opportunities for adapting the results and implementing them in other industries and SMEs which only seldom participate in the type of programme being studied here. Institutes are a particularly valuable resource in the dissemination of technology to SMEs.

New companies

We have seen a few examples of new companies being formed as a result of the five programmes and some examples of micro-companies growing up. However, these are the exception. We note that three PhDs, whose research training was partly funded through the five programmes, are running their own companies which may in the future be developed further.

Open innovation

A number of companies, especially engineering companies, say they have changed their working methods, sometimes radically. “At one time, we knew everything, but we've grown up and realised there are others who possess valuable knowledge", as one representative of the major company puts it. This realisation means there is a need to have absorption capacity as well as an ability to find suitable R&D actors to collaborate with. Also, a capacity to keep up to date with international developments in technological fields relevant to the company. This development in working methods has long been under way within the major manufacturing companies but is now spreading to smaller companies and SMEs.

The origins of impacts

The five programmes which this impact analysis has focused on are:

- ITV (IT in the engineering industry, 1996–2004), a programme which aimed to support the collaboration between CTH and IVF by helping CTH develop research into production technology. The project was largely defined by the R&D implementers themselves with industry contributing to reference groups
- TIP (Product development in the manufacturing industry, 2002–2005) which was by and large of similar origins but with more R&D implementers which were distributed across Sweden. The project was largely defined by the R&D implementers themselves with industry contributing to reference groups
- KSP (Complex assembled products, 2003–2009), with a setup in which projects continued to be largely defined by R&D implementers but industry now contributed actively to the R&D work. This means that projects needed to be more strongly established with companies if they were to be interested in participating
- EP (Efficient product development, 2003–2009) which had the same design as KSP
- MERA (Manufacturing Engineering Research Area, 2005–2010), which was quite different from the other four programmes in that the participating companies (particularly automotive manufacturers, plus subcontractors and companies outside the automotive industry) have their own budget shares for division between projects relevant to themselves, provided the applications fulfilled set quality requirements. 16% of the public funds in MERA went to the companies themselves. MERA was more focused on developments in research than the four earlier programmes and, as already mentioned, was a fixed-term, government assignment.

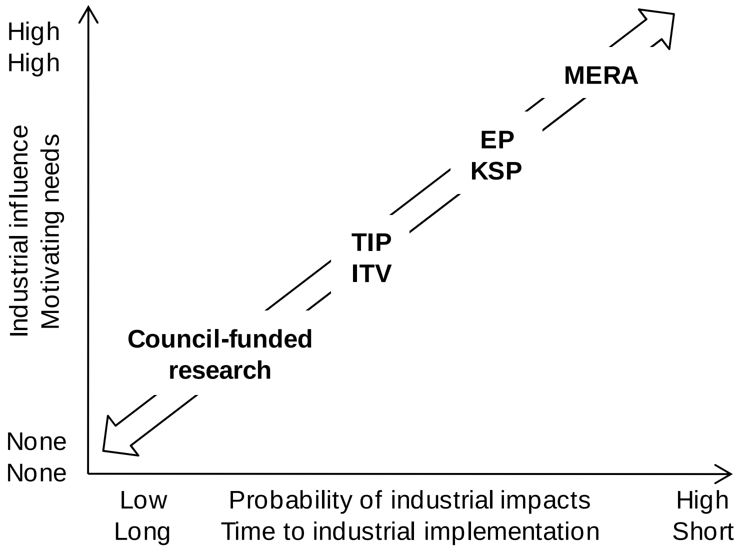
Since the public R&D grants for all intents and purposes went to fund work carried out by universities and institutes, the impacts achieved in industry are indirect. Public money is converted into work by R&D implementers who produce R&D results and examinees, which in turn can be absorbed and provide impacts in industry.

Simply put, the five programmes belong in three different programme generations in which industrial influence and industrial participation has gradually increased. When the R&D implementers are those with agenda-setting privilege and industry participates in reference groups (as with ITV and TIP), it is reasonable to assume less likelihood of R&D results finding industrial use, at least in the near future. This is because the direction tends to be more "academic" (as companies do not have the same opportunities of influence) and because companies do not come into direct contact with the work in the same way and thus risk underestimating its usefulness. However, this type of instrument does not preclude this from happening if R&D implementers are attentive to the needs of industry as illustrated by IT Geometric Assurance.

When agenda-setting privilege is shared between the R&D implementers and industry, with industry able to take an active part in the work (as with EP and KSP), projects become more practical and the likelihood increases of them leading to impacts industry. When industry has agenda-setting privilege as with MERA, and actively participates in the work whilst the focus is more on development than research, projects become even more practical and the likelihood becomes very great of them leading to impacts in industry. It can be noted that key individuals from industry participated in the development of all these programmes, meaning that the programme evolution we are seeing is partly the result of corporate influence at programme level. For this reason, industry also has an indirect influence on the R&D direction of R&D implementers.

This correlation can be described schematically – and very much simplified – by Figure 2. Simply put therefore, strong industrial influence and active project participation leads to rapid and extensive impacts, which begs the question what kind of impacts? There is a risk of a programme such as MERA leading to short-termism and the satisfaction of short-term needs at the expense of more long-term technological development. There is also a risk of lock-in, in which established companies stand in the way of new actors and radical renewal. However, such counterfactual reasoning is naturally difficult to demonstrate. At the opposite extreme, in which researchers devote themselves to curiosity-driven research, there may be no impacts at all (see bottom of Figure 2).

Figure 2. Schematic illustration of the correlation between industrial influence on problem formulation and anticipated industrial impacts.



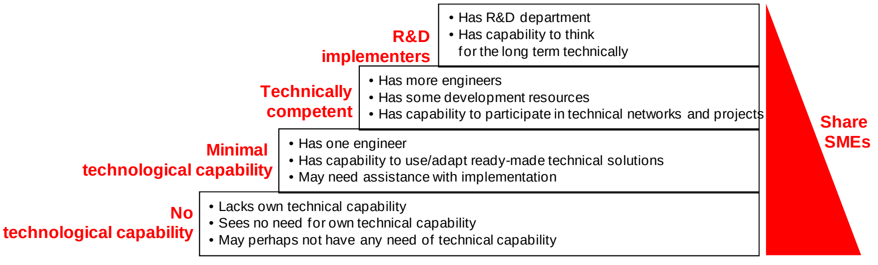
We see a cadre of university researchers, presumably self-appointed, willingly and successfully taking on industrial issues regardless of the types of instrument concerned. In this regard, there has been a change of attitude since the start of ITV. Previously, many researchers considered (and many still do) that needs-driven R&D was not “good”. At the same time, according to one professor at CTH, “15 years ago, production was something the cat dragged in and now it’s one of CTH’s eight areas of strength receiving strategic research funds”, which can probably be attributed to ITV. There are indications, both in the empirical data of this study and in previous impact analyses and evaluations we have conducted, of most R&D milieus at universities and institutes being able to strike a good balance between working in industry-led projects and researcher-controlled ones. However, this assumes both opportunities are present. An R&D milieu at a university entirely controlled by industrial needs would probably find it hard to assert itself in the long-term, both from an academic perspective and from the perspective of having something to offer one’s industrial partners, long-term.

If the aim is to achieve industrial impacts, we believe it is very important for companies to participate not merely in the problem formulation but also to take an active role in the R&D work. Such active involvement radically increases the likelihood of first-order impacts resulting as per Figure 1. It is likely that the seeds of impacts germinate in the dynamic between companies and R&D implementers created by active participation, as well as between companies.

For those companies that actively participated in projects, creating second-order impacts is thus largely an in-house corporate matter (see Figure 1). Moreover, if the aim is to achieve spillover to other industries and companies, large and small, which are not participating in projects, then institutes play a key role in achieving such second-order impacts. Universities can also help disseminate technology, but institutes have a more suitable business concept and staffing for this purpose, particularly where it concerns dissemination to SMEs.

It is important to note that with few exceptions, it was generally the established and often large companies with their own R&D competence and technical absorption capacity that participated in the five programmes and that there was only a very modest involvement from SMEs. There are several reasons for this, including the fact that SMEs may find it difficult to set aside the resources (most often time) required for co-financing and that the time perspective is too long. Basically, industry can be structured as a technical competence hierarchy, see Figure 3. Most participants in the five programmes appear in the two uppermost categories and with a few exceptions, these are the large or relatively large companies. A small number of the SMEs on level 2 ("technically competent") have participated in the five programmes. It is highly unlikely that any SMEs from level 3 ("minimal technical capability") participated at all, although there may naturally be exceptions. It is chiefly SMEs at levels 2 and 3 which institutes are able to reach in their capacity as technology brokers.

Figure 3. Technical competence hierarchy in industry.[3]



[3] Inspired by E. Arnold and J. Bessant, "Nutek Evaluation of the AMT Action Areas", Nutek, 1993.

Policy conclusions

The impact analysis results in a number of possible conclusions regarding policy.

Industrial influence

Industry-led R&D programmes fulfil a vital function for industry's technology supply and competitiveness. However, this applies in the main to established (and particularly large) companies with considerable in-house R&D competence and absorption capacity. Still, industry-led R&D programmes carry risks in terms of lock-in and short-termism. From an innovation systems perspective, this need not necessarily pose a problem if such programmes are supplemented with programmes with a more long-term focus and a lower degree of industrial influence.

Continuity

Short programmes such as MERA (the last of the five programmes to commence and a short-term government assignment) are normally characterised by short-termism, whilst long-term programmes stimulate more long-term and strategic thinking focusing on the amassing of competence and human capital. A programme as massive in monetary terms as MERA may also leave a vacuum which will probably be detrimental to the development, particularly for the R&D implementers. At the same time, the relative continuity which the five programmes offered for some R&D implementers and companies, particularly in conjunction with other financiers' programmes, has been very important to those who contributed. It is therefore probable that an increased degree of predictability and continuity in the public funding would benefit both R&D implementers and companies.

Overall coordination between R&D financiers

In terms of both the balance between different types of instrument (degree of industrial influence) and need for continuity, there is a partially unexplored potential, seen from the systems perspective we presupposed in this analysis. Increased coordination between all VINNOVA's and SSF's instruments for the purposes of best developing the innovation system should produce a profitable outcome and implementation of a plan as to how these organisations' efforts could be geared up through a Swedish strategic participation in the EU Framework Programme. For some actors, KKS is an important financier whose instruments should naturally also be part of such a coordination. Although there are probably significant practical challenges in coordinating formal independent R&D financiers, there is nevertheless unexploited potential here which could be utilised.

Focusing or pluralism?

A very important strategic issue is whether VINNOVA should make focused and long-term efforts or spread its favours across many subjects and R&D implementers. The answer is not obvious, but the wish to benefit pluralism and competition should probably be weighed against creating a critical mass with R&D implementers and thereby benefitting the build-up of international competitiveness. The ratio of each krona invested in an established R&D milieu probably gives a considerably larger yield than if it was invested in building up a new milieu. On the other hand, it is clear that recruitment of both graduates and research-trained people mainly takes place regionally (few people want to move far, if anywhere) which indicates a broad participation by R&D implementers.

Institutes and universities

Institutes are important links in the technology dissemination chain, particularly for dissemination to SMEs. If institutes are to maintain their competitiveness within a given area in the long-term, they need to be guaranteed resources so that they themselves can continually develop their competence. Institutes are also strongly dependent on close collaboration with researchers at universities in order to keep up to date with the frontiers of research. When such a partnership is effective, it creates major benefits for everybody involved; but when absent it can lead (in the worst cases) to short-term gains without any sustainability or to a limited dissemination of R&D results. We can confirm that successful institutes always seem to have a strong relationship with at least one university. One conclusion from this is that R&D efforts, at least the large and long-term ones, should include R&D implementers at both universities and institutes in order to achieve maximum spillover.

If the intention is only to spread knowledge about a new technology to industry, chiefly SMEs and for a limited time, then investments in technological dissemination of the kind made by Nutek during the early 1990s to spread knowledge about FFF are probably effective. However if the aims are greater than this, such as establishing R&D within an area, strong Swedish companies for the long-term or stimulating the creation of new companies, then these kinds of efforts would probably be wholly inadequate.

Open innovation

The increasing emphasis on open innovation thinking, which has now also spread to SMEs, places new demands on the public part of the innovation system. The forms of work and funding within the five programmes are better suited to larger companies than small ones (although one of the five programmes had a special SME call for proposals), so what choices of instruments are needed in order to satisfy SMEs' increased need for technological development and innovation support? It may be that instruments beyond VINNOVA's Research&Grow and competence development tools for institutes are needed. Closely connected with this issue is why so few new companies have been started within the areas covered by the substudies and why some of them have found it so difficult to grow (even though access to technical R&D can never be a sufficient condition for setting up and growing companies). In this context, several interviewees in the world of institutes have indicated shortcomings in the policy mix, as they have found it difficult to raise adequate financing for technological dissemination to companies wanting to take the subsequent steps towards commercialising R&D results.

Furthermore, we can confirm that:

- In several regards, there are inbuilt conflicts of interest in various partners' expectations of public R&D efforts, such as:

Achieving rapid impacts	–	Achieving the creation of long-term competence and human capital
Building critical mass and international competitiveness	–	Generating a basis for recruitment throughout Sweden
Satisfying the needs companies spying the needs of SMEs	–	Satisfying the needs of SMEs
Investing in universities	–	Investing in institutes

  Thus there is reason for very pronounced clarification of what the aims of a specific initiative are and evaluating what may be compatible goals in each context

- Several of the verified impacts (e.g. qualified licentiates and PhDs) have come about despite not being clearly expressed goals of the five programmes
- In many instances, the automotive and aviation industries are driving the development of technology, but through the agency of R&D implementers there is a good chance of adapting R&D results and implementing them in other industries and SMEs. The R&D being conducted within areas relevant

to the automotive and aviation industries can thus be considered important far beyond these industries

- Public R&D programmes with the active involvement of industry are far more important than we realise if we only look at the size of public efforts in relation to companies' own. The fact is, public efforts presuppose more long-term thinking than is normally permitted within corporate in-house funded R&D activity.
- A systems perspective in which the efforts of all R&D financiers' are deemed necessary in order to reliably establish a cause-effect correlation. Only in exceptional cases would it be possible to unequivocally attribute an impact to the R&D programme of an individual financier
- If this impact analyses had focused on other areas within product manufacture, to some extent other and possibly different impacts could have been confirmed.

Functional sales substudy

Functional sales means that a hardware-producing company sells (and guarantees) a *function* – retaining ownership of the hardware instead of simply selling it and allowing the customer to worry about its functionality. An everyday example of functional sales is a supplier selling a copying function rather than a copier. Functional sales are distinct from leasing or renting because in these latter instances the customer pays whether or not the product works and it always relates to the same physical product. With functional sales, the customer is guaranteed a function (a *functioning product).* This substudy also includes functional products, meaning products developed specifically for functional sales.

Based on the empirical data we have gathered, Figure 4 describes our belief that the impact logic within the area has developed and how the public efforts have led to impacts in industry. Our analysis has focused on what may be considered Sweden's two most important R&D milieus in the area, at LiU and LTU. The R&D activities have been implemented in four of the five programmes (not MERA) and especially for LTU milieus that also come under other VINNOVA programmes, plus ProViking at SSF. These activities have very gradually led to direct results. Over time, these results have developed into first-order impacts with both R&D implementers and participating companies. In the longer term, these impacts may ultimately lead to second-order impacts.

Figure 4. Impact logic for functional sales/products. Yellow boxes indicate results and impacts in the R&D implementers' world, blue boxes impacts on companies and green boxes common activities, results and impacts.

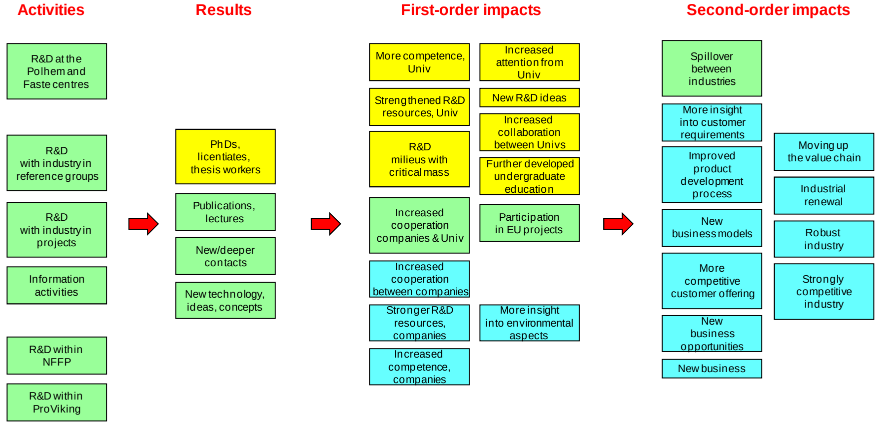


Table 1 shows the number of research-trained people who were co-financed in projects under the five programmes and relevant to the functional sales area. All these candidates still have research-relevant work duties.

Table 1. Compilation of candidates in functional sales. "Share" means share of "Total".

	Licentiates		PhDs	
	Number	Share	Number	Share
Total	6	–	11	–
Of which active in universities	3	50%	6	55%
Of which active in institutes	1	17%	0	0%
Of which active in companies	2	33%	5	45%

Impacts for industry

First-order impacts

If we look at the results from the questionnaire conducted in the study and the question of what the companies' participation has led to, the three most frequent responses are: competence-developed staff (80%); development of the company's service offering (50%); and use of processes, methods or tests that were new to the company (40%). If we look at the perceived degree of goal fulfilment on the part of the industrial respondents in relation to expectations, we find that 67% consider themselves entirely or largely satisfied.

The capability to work out balanced functional sales offerings sets very high and advanced standards of those designing them and in many cases requires research competence. It was this realisation which, in the late 1990s, made Volvo Aero (VAC) raise the training level of its own R&D organisation and cooperate with external R&D suppliers. Since there was scarcely a surplus at that time of employable research-trained people, both aspects of this realisation essentially dictated a collaboration with universities and publicly funded R&D programmes.

In the second half of its existence, the Polhem Competence Centre (which ran from 1995-2006 with VAC taking an active role) featured an increasing degree of research in functional sales and functional products which produced several PhDs. Naturally, the PhD programmes in functional sales increased in number with funding from the National Aeronautics Research Programme (NFFP, many projects), SSF's ProViking, the Knowledge Foundation, the VINN Excellence Center Faste and VAC itself. According to VAC, among the first-order impacts which can be said to have emanated from these public R&D initiatives were 26 PhDs and eight licentiates within the area (there are still a further 10 active doctoral students) as well as a significantly elevated level of knowledge in functional sales and functional products within the companies which took part in the projects, particularly those participating in Polhem and Faste.

The partnership between VAC and LTU has a long history. Contacts were initiated back in 1978 when LTU held a course in product development and applied mechanics which interested VAC. The partnership with the School of Industrial Design at LTU was initiated in the mid-1980s and funded partly by the Swedish National Board for Technical Development (STU) and Nutek. It progressed yet further through VAC's participation in the Polhem Laboratory and because in 1991 the company's then head of research was appointed acting professor of LTU's Division of Computer-Aided Design. At that time, the research related primarily to product development and only later was the emphasis shifted to research and service development and their impact on the overall product development process (hardware + services). Very gradually, LTU introduced the new research area of Functional Products for which VAC's then head of research was guest professor from 2005-2007. Now, one of the former doctoral students from this R&D milieu has a professorial chair in the same subject and another of the doctoral students, now working at VAC, is acting professor in the subject. VAC's current head of research is another of the doctoral students from this milieu.

It was during a ProViking project at LTU that Sandvik Coromant was inspired to fresh thinking regarding the actual concept of functional sales. This contributed to the addition of an internal interdisciplinary project comprising both technical departments and "the business side". Without this participation, it is unlikely that the group which resulted from the project would have existed; this would have meant the continuation of traditional product lines. Sandvik Coromant believes the projects it participated in at LTU gave the company building blocks with which it could create functional products. It is still not possible to point to a product catalogue and say that "this is an implementation" – additional internal work to further develop the knowledge is necessary.

Likewise, a representative of Hägglunds Drives states that by participating in the activity at LTU, it was possible to realise the value and necessity of increasing the internal competence. Also, having been a relatively small company in the 1990s whose university contacts were through thesis workers, it now has two dedicated industrial doctoral students and a third who received their PhD three years ago. Hägglunds Drives is now also in touch with Uppsala University (UU), KTH and LTU within tribology research. Historically, Hägglunds Drives has focused a great deal on building up practical experience, even whilst some researchers seemed to think simulation alone was enough. However, it has had a productive encounter with industry and academia in the experimental verification of models constructed by universities and this has benefitted both parties. Hägglunds Drives also points to the opportunity of cooperating with companies like VAC and Sandvik and in this regard, LTU has served as a good catalyst; without LTU, this type of partnership would not have been possible. Such partnerships are important in order to gain an understanding of how other (and often larger) companies regard the future and what problem areas they see. This has given Hägglunds Drives the opportunity to confirm whether it is on the right track. It is also much easier for the "industrial perspective" to break through in academic research if larger companies participate in the work.

Subsequently, the many Swedish PhDs and doctoral students have benefited VAC (and LTU) by making them more attractive as partners in the European research arena, where they have also been very successful. For example, VAC participated in seven aviation-related R&D projects within the Fourth Framework Programme (RP4, 1995–1998), 12 projects in RP5 (1999–2002) and 11 projects in RP6 (2002–2006). VAC's then head of research also contributed to the European aviation strategy entitled Vision 2020 and the European Commission's Work Programme (in practice, call for proposal texts) in aviation in both RP5 and RP6. On these occasions, he took the opportunity to argue for functional sales and functional products which, amongst other things, resulted in the EU project VIVACE which lasted 2004-2007 and in which VAC and LTU participated from the Swedish side. VIVACE dealt with the streamlining of product development in a global project including production of new business and service models.

A representative of Alfa Laval explains that they were aware of the business opportunities which functional sales could offer but did not understand how to implement them. Participation in an EP project led by LiU involved a reference group convening several times a year to discuss a theme often connected to the hosting company's particular problem. Occasionally, research findings were presented from the academic side. Through the group, Alfa Laval was aided in identifying its business opportunity and working with "straight business development", which led to a business model. Traditionally Alfa Laval had given away software in conjunction with new sales, but it now realised this should be sold. The Alfa Laval representative considers that given the way things were in terms of knowledge when the project started, they have come a long way by working with the business plan – it was "a wonderful experience".

One university researcher believes he is seeing an increased awareness of the importance of research amongst companies. Corporate collaborations with universities have also become clearer and more rigorous as well as more strategic in that they do not now spread their partnerships across so many different R&D implementers. Companies have quite simply become more professional; this is particularly apparent through the increased successes of the EU Framework Programme. Furthermore this researcher believes that, taken over a decade, really major changes have occurred. Companies have gone from being closed and rather suspicious of each other to now openly accepting national cooperations. This makes them much stronger outwardly, including within the EU Framework Programme. On the whole, companies have more of a presence in the R&D arena.

Second-order impacts

VAC is perhaps the company which has benefited most from public R&D programmes in its development towards an increased share of functional sales. This is largely because the company had such a leading position in both the Polhem and Faste centres at LTU. The company's representatives mentioned several examples of second-order impacts. The now almost classic example of functional sales, the service *power-by-hour* (or kWh for stationary turbines), are still current and a commercial reality for VAC. VAC is also devoting itself to functional sales in straightforward maintenance contracts for old products with a long useful life, sold purely as hardware. Unlike its first faltering steps on the pathway of functional sales, VAC now possesses the capability to put together mutually attractive customer offerings. In this context, the university research and clearly increased in-house researcher competence are aiding[4] the company in a fundamental understanding of demand and economics, a prerequisite for judiciously considering the design of customer offerings. A couple of representatives of VAC explain that the principles of functional products have partly been implemented in the product development process which is speeding up the process and enabling it to bring about more suitable results and products with expanded functionality i.e. functional products.

A representative of Hägglunds Drives says the company has gone from supplying components to supplying systems. There is now also discussion about supplying functions, which would serve as an extended guarantee and include a number of commitments from the company's side. The company has found that it can be paid to a greater extent for knowledge. This development is based on the genuine R&D investments made by the company at the beginning of the 1990s which are now beginning to bear fruit. Hägglunds Drives believes it has

[4] According to its own information, VAC has increased the number of PhDs employed from two in the 1970s to some 50 today.

become more proficient in the actual concept stage of the product development process. The company is now basing its product development on theories where previously it relied entirely on testing. This is now mostly carried out to verify developed models. The company has largely built up this simulation competence in collaboration with universities under the umbrella of programmes funded by VINNOVA. For example, the tribology research at KTH has led to useful life increases of up to 20-30 times for the company's engines; this is now being implemented. Also, the company can now get a much better understanding of how customers use its products because there is much more opportunity to measure how they are used (energy consumption for example).

Impacts for the R&D implementers

Concerning the research infrastructure, two R&D milieus have shown strong growth and now seem to have reached a critical mass. Representatives of both milieus agree this would not have been possible without VINNOVA funding. At LTU, this development has also resulted in the new research topic of Functional Products which has its own unit in the Department of Applied Physics and Mechanical Engineering.

The questionnaire to project managers at universities and institutes reveals (according to 46% of the respondents) that participation in the five programmes is highly significant to increased international cooperation. For 89% of the respondents, participation in the five programmes led to new R&D projects and of these, 88% involved partnerships with companies such as ABB, AB Volvo, BAe Systems Hägglunds, Ericsson, GE Healthcare, Green Cargo, Kværner Pulping, Sandvik Coromant, SCA, Scania, SNA Europe, St. Jude Medical, Thule and VAC.

An industrial representative with in-depth understanding of research and educational issues thinks that the researchers had a radical influence on graduate engineer training. LTU has a doctoral course in functional products and several undergraduates and doctoral courses in various aspects of product development. A researcher at LiU explains that next year, following four years of preparations, a new undergraduate course is starting in IPS Engineering with an initial 40 places.

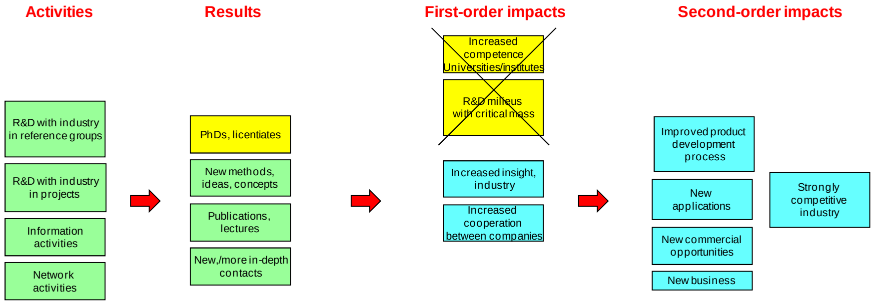
Free-form Fabrication substudy

Free-form fabrication is normally more formally called “additive layer manufacturing”. It involves a number of (often rather different) manufacturing techniques whose common denominator is building up an article layer by layer, and in some variants particle by particle direct from CAD data, thus enabling production of the desired product.

Using FFF, three categories of products can be produced: 1) structurally non-solid prototypes, 2) small-scale or one-off manufacture, e.g. implants 3) finished, structurally solid products in varying sizes. The FFF technology is best suited to small objects with complex shapes manufactured in short runs. There are a number of good arguments for using this technology. The reason most often put forward in our interviews was that this technology enables production of actual, three-dimensional prototypes; a physical model is superior to a computer model. This improves the communication in the design and action process. With FFF there is a very direct link between what the designer created in the computer and the final component. Other advantages of the FFF technology is that it drastically reduces time to market, it reduces time and cost of producing moulds, such as with injection moulding in plastic and it can produce parts which are very expensive or difficult to produce in other ways. FFF technology originated in the US and was introduced to Sweden in 1988.

Figure 5 shows how we tried (on the basis of available empirical data) to recreate what actually occurred as a result of a programme effort in FFF made by Nutek between 1990-1996. However this is not one of the five programmes being focused on in this study. In this impact logic, the first stage consists of the activities funded by Nutek. The second stage identifies the results which the initiatives brought about. Following this are first and second-order impacts. The impacts that are crossed out have *not* been observed by us and we will return later to what we believe this means.

Figure 5. Impact logic for FFF. Yellow boxes indicate results and impacts in the R&D implementers' world, blue boxes impacts on companies and green boxes joint activities and results.



Impacts for industry

IVF was quick to notice the FFF technology and with funds from Nutek began to spread knowledge about this during the first part of the 1990s. IVF's efforts mean that a number of companies and individuals within the engineering industry had their eyes opened to a new technology. The increase in competence which took place within companies meant they gained more insight into FFF methods and concepts. Above all, the activities mean new and more in-depth contacts between companies; several interviewees describe this as a pioneering period in which the members of "FFF Sweden" crystallised and got to know each other. Also feeding into this was the newsletter and website for which IVF had production responsibility.

First-order impacts

IVF's information initiatives meant that industry-relevant knowledge about a new technology became available to a number of engineering companies. However it was not just the technology that got spread; actors with their own individual experiences were linked up. Of particular importance in this context was the individuals who participated; who had what sort of equipment, what machines were good for what sort of prototypes etc. Through these activities, companies gained more insight into the possibilities of the new technology. The network that IVF assisted so greatly in creating survived in various contexts and groupings. It is very clear that the institute fulfilled its task excellently.

Second-order impacts

During the latter part of the 1990s and as new and cheaper FFF equipment became available, the number of small companies starting to offer services increased. These were machines which could be located in offices and the new companies, or service agencies, offered commission-based model manufacture. In many instances, these service agencies were run by those who had been involved in networks created through IVF's activities.

This led to an improved product development process and new applications, which in turn probably led to new commercial opportunities and new business. It seems logical and almost inevitable that this is the case, however based on the empirical data of this study it is actually impossible to prove that this is what happened. Many interviewees indicate that FFF is now a technology integrated into design, construction and prototype manufacture as one "tool" amongst many. "Nowadays, nobody thinks of it as a separate technology", was the way one person put it and since this technology is not (or has not) generally been the core activity for many of the companies, it is almost impossible using normal working methods to trace and evaluate the significance of this particular technology to these companies.

Of those companies which currently have FFF as the core of their operation, the majority manufacture end-use products or prototypes, whilst many are just agents or distributors of FFF products. These are mostly small or medium-sized enterprises (SMEs), sometimes with only two or three employees. The largest company employs around 50. Of these 20-plus SMEs (around one third of which are agents or distributors without their own production), most were involved in the network activities run by IVF during the 1990s. In three cases, we can trace the threads back to direct subsidies of companies from Nutek or VINNOVA, specifically Arcam, fcubic and Prototal.

In 2008, Prototal (founded in 1998 as a spin-off of Electrolux) had 40 employees and a turnover of SEK 68 million. The company founder attended the meetings and the network which IVF constructed. Arototal then participated in the MEDeFFF project which between 2002-2004 was run under the umbrella of VINNOVA's AIS programme. For 2008, FFF-related activity makes up around 10% of Prototal's total turnover and in turn, according to the company's head of marketing, the medical applications (an area which the company found through its participation in the AIS project) account for only "one tenth of one percent" of this. Accordingly, medical applications of FFF are not something which the company can support itself on – "not in the near future!". The participation in MEDeFFF is described by the head of marketing is an exciting attempt within a new business area, but the outcome of Prototal's part of the project participation did not go as hoped. However the company is still active within this niche.

fcubic is a spin-off from IVF. The company was started with the aid of grants from Nutek and the machine which the company is still utilising was paid for by Nutek. The company has two employees and has not yet commenced manufacturing on any large scale. Its turnover has varied greatly and during the broken financial year 2008/2009 totalled SEK 92,000.

Through its founder and first CEO, Arcam was a member of the early IVF network. The company makes machines which manufacture components in steel and titanium and now has a niche for titanium parts, a role in which it is considered "outstanding" on a world level. The technology used is called electron beam melting (EBM) in which an electron beam melts metal powder at very high levels of precision. Commercialisation of the machines began in earnest in 2002 and in the last five years has found interesting applications particularly within orthopaedics and aviation. For example, in December 2008 the company received an order for four EBM machines to manufacture turbine blades in titanium aluminide (to achieve low weight in the construction of aircraft engines).

Arcam has grown into a successful international actor due, amongst other reasons, to two VINNOVA-funded projects on medical applications of FFF technology, both of which Arcam project-managed. During 2005-2008, Arcam was granted SEK 1.2 million from VINNOVA for the two FFF projects being conducted in partnership with the University of Gothenburg (GU), Integrum and Swerea IVF. These projects made it possible for the company to venture into a new market. At the next stage, Arcam and Swerea IVF produced an EU application in respect of implants with layer-to-layer production. The application was a late arrival, but despite this Arcam managed to secure a world-leading position for the implant. The contacts and knowledge which the company had built up were a direct reason for the company joining the VINN Excellence Centre of Biomaterials and Cell Therapy (BIOMATCELL) (led by the same professor at GU that the company had collaborated with on the two previous projects). During this time, Arcam also received funding from Research&Grow.

The company considers that overall VINNOVA's supporters had a catalysing effect and Swerea IVF has emphasised the importance of the VINNOVA support. Swerea IVF's role is worth a special mention in relation to Arcam's current prominent position within medical applications. Swerea IVF was project manager for the VINNOVA project MEDeFFF and with the knowledge it accrued through this project went on to other efforts. It was through Swerea IVF that Arcam later had the opportunity to apply its technology to the medical field. The company would not have been able to do this without the opportunity presented it by Swerea IVF.

Arcam's successes are only partly a result of initiatives from Nutek and VINNOVA; the external actor which has been most significant to the company's development has been Industrifonden. In 1999, Industrifonden offered a loan of SEK 6 million and the main reason for this was because the company was changing technology. A representative of Industrifonden describes it in terms of the company having an "entirely world-leading technology in an area that nobody knew it would be applicable to in the beginning". Industrifonden got involved with Arcam in the belief that "it was going to produce moulding tools in steel in order to make injection moulded plastic products with unusual geographies" for clients such as Volvo and Ericsson. The way did not prove to be easy, since the tools were difficult produce and because the product value in steel was too low. When the company went over to titanium, the way was open to new opportunities and the emphasis has shifted from the engineering industry to implants and the aerospace industry.

FFF is now an integrated part of a more efficient product development and manufacture in the Swedish manufacturing industry. Many companies now have the technology as one of their tools, however based on the empirical data we gathered it is not possible to substantiate whether this can be linked back to Nutek's/VINNOVA's efforts. Naturally it is impossible to ignore IVF's initiatives as they probably facilitated the spread of the technology. However, it is not possible to demonstrate any connection between IVF's initiatives and what we can see today.

Impacts for R&D implementers

Within the five VINNOVA programmes that we gave particular study, there is only one project within the area of free-form fabrication. A further seven FFF-related applications were submitted to EP and KSP, but were all rejected:

- EP: One each from LTU, KTH and Swerea IVF
- KSP: Two from Swerea IVF and one each from Lund University (LU) and KTH

Consequently, the volume of applications within FFF has been low and according to VINNOVA, the applications to EP and KSP above were of low quality. Fresh thinking was a requirement in EP and KSP, something which applying R&D implementers (with the exception of Malmö University (MaH)) were unsuccessful in satisfying. The project which MaH led within EP from 2002-2004 was a PhD project and having obtained their doctorate, the student in question is now working for Rolls Royce. At a later stage, the project brought about a partnership between MaH and the companies Arcam and Anordica.

It is clear from the impact logic presented above that we have been unable to demonstrate any clear impacts on the country's universities as a result of the initiatives which VINNOVA and its forerunner Nutek conducted within FFF. The fact that the official efforts seen not to have had any lasting effect on Swedish R&D implementers is chiefly because they enjoyed almost no funding within the FFF area. With the occasional exception, the subsidies granted by Nutek during the 1990s and VINNOVA subsequently had gone to institutes (primarily IVF) and companies. There were no parallel activities or FFF-related efforts from these or other government actors in the university research. Accordingly, there are now no researchers driving the area forwards within the engineering industry.

The only second-order impact we found amongst R&D implementers was the above-mentioned VINN Excellence Center, BIOMATCELL, of which FFF for medical applications comprises a part. BIOMATCELL can be traced back to a VINNOVA project and would probably not have come about without this initial funding from VINNOVA. Similar to the second-order impact we discussed in relation to companies, this result cannot be attributed to VINNOVA's five programmes but probably to programmes covered by a broader systems discourse.

Industrial IT substudy

Industrial IT is a very broad and virtually all-embracing concept as IT is used in all conceivable industrial applications. Every attempt to enumerate the most common fields of application could probably be criticised for not being correct or balanced and for this reason, we have chosen to refrain. VINNOVA regards Industrial IT in a product manufacture context as two areas:[5]

- Use within production and production control with relevant areas including measurement, measuring systems, sensors, continuous monitoring and control, traceability, security and new methods of increased productivity.
- Use within the development stage of production, with natural areas including visualisation, modelling, simulation and verification.

Even if we had not chosen to limit this substudy to Industrial IT in a product manufacture context, we would probably have taken on more than we could manage. Even with these limitations, the area is incredibly extensive and would probably have needed its own study on the same scale as the whole of this impact analysis in order to be done properly. It was therefore decided in consultation with VINNOVA to draw the demarcations according to two guidelines:

- Geometry Assurance, which in this context relates to all activities aimed at minimising the impacts of geometrical variation in a finished product
- IT-assisted manufacturing processes of shaping, machining, heat treatment and assembly (hereinafter called "IT Process")

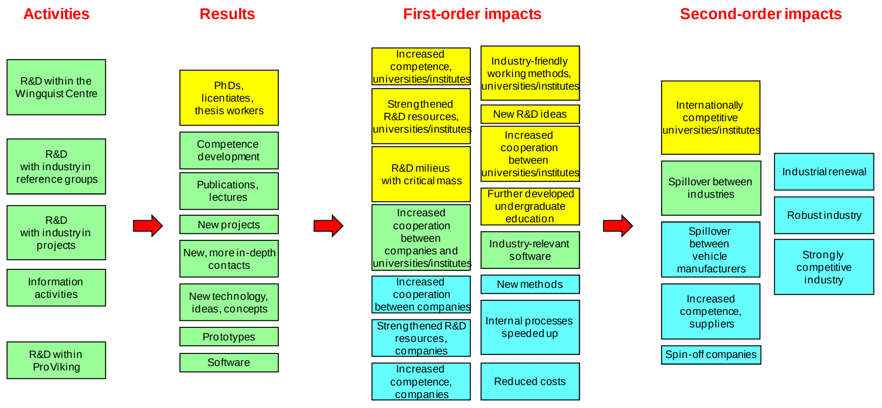
These demarcations, the former of which may be regarded as a subset of the latter, were made chiefly in the light of VINNOVA's understanding of what type of R&D project was contained within the five VINNOVA programmes from which this study is primarily attempting to trace impacts. The advantage of these demarcations was that they create a reasonably "graspable" object with a manageable number of R&D implementers. This allows the possibility of in-depth data collection and analysis and thereby the ability to identify relevant impacts. Naturally, the drawback is that we have not in any way covered the story of the entire area of Industrial IT and thus definitely miss out on quite a number of success stories. Nevertheless, we believe that the account below gives valuable

[5] "Call for proposals 2004 in VINNOVA's knowledge platform, Effective Product Manufacture Stage One", VINNOVA, April 2004.

insights into essential developments in parts of Industrial IT and public R&D financiers' roles in this. **To sum up, we make no claim whatsoever that this substudy covers the entire area of Industrial IT; only a portion of a very large area.**

The early impacts of the public R&D funding which we are able to observe now are depicted schematically in Figure 6. In principle, the same impacts are covered by both Geometry Assurance and IT Process.

Figure 6. Impact logic for Industrial IT. Yellow boxes indicate results and impacts in the R&D implementers' world, blue boxes impacts on companies and green boxes common activities, results and impacts.



Of the 50 PhDs which have been part-funded by the five programmes, 42 have worked in projects related to Industrial IT. Correspondingly, 31 of the total of 43 licentiates have worked in projects related to Industrial IT.

Table 2. Synthesis of candidates within Industrial IT. "Share" means share of "Total"

	Licentiates		PhDs	
	Number	Share	Number	Share
Total	31	–	42	–
Of which active in universities	16	52%	18	43%
Of which active in institutes	3	10%	1	2%
Of which active in companies	9	29%	20	48%

Impacts for industry

Concerning industry, we are able to see certain first-order impacts for the first contributing companies and certain second-order impacts arising in the next stage for other companies.

First-order impacts

Development of industry-relevant software

Concerning Geometry Assurance, we have noted the development speeded up when Volvo Cars (Volvo PV) identified a need for simulation of something known as tolerance chains to cover the entire chain from design and construction to fitting of major parts on finished cars (particularly in regard to bodywork), thereby increasing the quality of the end product. However, it was realised that the necessary understanding and comprehensive knowledge was absent so an approach was made to researchers at centres as CTH. Thus, in principle, it was the company which identified problems and then brought the researchers in to try and describe and solve them mathematically.

One of the first partnerships which resulted in industry-relevant software was the 3D Tolerance Management project which came under the Nutek ITV programme. Volvo PV's comprehensive quality philosophy required the development of better software than was available at that time and this was done in partnership with CTH. The result was the now commercially available software RD&T, which started off with the Volvo 850 and has achieved widespread use in the production of new models at Volvo PV. This partnership also led to the formation of the company RD&T Technology AB, which has since also cooperated with others such as Volvo Trucks (Volvo LV), Saab Automobile, Ericsson, Geometrics, Caran, Semcon, Volkswagen, Audi, Pininfarina and the Lear Corporation. The R&D implementers took charge of the development of the mathematical algorithms whilst industry gathered production data to serve as input for the models being built up by the R&D implementers. Since gathering production data for verification of simulation results requires access to a factory, it would in principle have been impossible for the R&D implementers to conduct the whole project themselves. At the same time, companies do not have the theoretical competence which would be required for development of the algorithms. Once the R&D implementers have developed their algorithms, industry verifies these in an actual production setting.

Within IT Process, a number of different simulation methods have been developed in partnership between companies and R&D implementers to the benefit of companies. These include: models to predict the mechanical properties of welded joints; simultaneous hardening and shaping of drill steel in order to predict mechanical properties, tool wear and maintenance needs; and structure of corrosion protection and how paint particles attach to the substrate during painting. New cost models, working methods, standardisation and digital factories have also been modelled.

Internal working processes developed and quickened

In regard to Geometric Assurance, we can see that the software developed in conjunction with the researchers has resulted in companies' processes of design, construction and mass production moving considerably faster. Companies' working methods have also changed. Rollout of the RD&T software in the Geometric Assurance process is reputed to have helped Volvo PV shorten its production lead time for a new model by about 25%. It took 11 years to bring out the 850 but the lead time for bringing out new models is now down to a cycle of three years.

There are also examples of work processes being speeded up in IT Process. Simulation of the structure of corrosion protection and paint is now taking place in real time at Volvo PV, where previously progress was made experimentally. This has meant a dramatic efficiency increase in the form of shortened development time and reduced material waste. Another project is expected to result in considerable time savings when new software simulating the welding process is rolled out. The system will primarily be used to solve problems arising in welding, but the idea in the future is that problems can be prevented from arising. In yet another project, the lead time to product launch has been shortened through the development of a virtual support tool for laser-hybrid welding in the construction process.

The simulation capacity which has been built up within both Geometry Assurance and IT Process has brought an increased understanding of the entire development and manufacturing process, as these can be explained in terms of a virtual chain consisting of different components. Since projects are increasingly trying to work with the entire chain and are also dependent on production data from factories, more direct work is taking place with the production departments instead of the central laboratories or development departments of companies. This in turn is leading to working methods close to the researchers spreading to other parts of the company, such as in Volvo PV where there is participation from those in production engineering to those working with robots and welding processes.

The contributing companies have also developed an understanding of how R&D implementers work and the major companies, at least, have no definite expectations of how and R&D projects will lead to directly applicable results. At the same time, these partnerships are a key factor in the ability to compete with rivals in other countries.

Development of companies' competence and methods

Where it concerns both Geometry Assurance and IT Process, we can also see that VINNOVA programmes have clearly contributed to competence development within companies. This is taking place through competence development of existing personnel and through thesis workers, industrial doctoral students and consultants. According to one outside assessor, industry now has better mastery of the whole picture (theory and practice) and can better articulate its problems. This means it is able to hold discussions with researchers on a different level than previously. Since companies have employed research-trained personnel they have increased their absorption capacity, in other words their capacity to collaborate with R&D implementers and benefit from and implement external R&D results.

According to one interviewee in industry, because of the company's participation in past VINNOVA projects there is now a more open attitude to employees wanting to take PhDs. A VINNOVA project has meant a change of materials for a certain product which has reduced scrappage and at the same time led to an increased production rate. Changing materials has also made it more cost-effective to produce the raw materials in Sweden than to import them from Asia.

Reduced costs

Within both Geometry Assurance and IT Process, the models and simulation tools resulting from projects allow development times to be shortened, occasionally dramatically. The same tools are also reducing the need for retrofitting or scrappage of defective products, which is also saving time and materials. Taken overall, this is leading to considerable reductions in development and production costs and thus increased competitiveness at the next stage.

Second-order impacts

Spillover between vehicle manufacturers

Within both Geometry Assurance and IT Process, we can see that the vehicle manufacturers have a prominent role in the development and introduction of software for the manufacturing industry. As collaborations between companies in different project groupings have become more commonplace, a spillover has also taken place to other companies within the automotive industry. Mobility between companies has also contributed to a transfer of competence and technology. Today, use of the RD&T software is a required element of design, development and manufacture of truck cabs. According to one interviewee, it is thanks to such things as the contact with Volvo PV that Volvo LV has been able to manufacture cab platforms for Renault. This spillover has been practically possible because Volvo LV has combined the use of consultants with internal competence development and recruitment. In several projects within MERA the partnership between vehicle manufacturers has been further extended, involving a progressive change in working patterns which has created increased openness and an exchange of technology.

Strengthening the competence and competitiveness of subcontractors

Within both subareas, we see that subcontractors' competence and competitiveness has been strengthened, largely thanks to the efforts of research institutes and particularly Swerea IVF. Several interviewees indicate that Swerea IVF has served as an important link between the vehicle manufacturers and their subcontractors which is often SMF. Through the RD&T software and Swerea IVF's own database tool DDBS, the entire subcontractor chain has been more effectively linked up with Volvo PV and a higher degree of quality assurance created at all stages. The vehicle manufacturers' requirements of subcontractors are increasing, which in turn is gradually raising their competitiveness against other customers. At the same time, Volvo PV's competitiveness is probably also increasing as the company can supply consistently high quality.

Formation of spin-off companies

The many years of work within Geometry Assurance have led to the formation of the spin-off company RD&T Technology AB in Mölndal. This company came about as a result of the partnership between Volvo PV and the CTH researcher, Rikard Söderberg. Within the ITV project 3D Tolerance Management, researchers identified that the modules for Geometry Assurance in commercially available CAD/CAM systems were only present for fault-tracing late in the production chain. As per its quality assurance philosophy, Volvo PV wanted to progress further in the chain and the researchers were thereby compelled to write their own simulation software. They located this outside the CAD system to avoid updating it every time the CAD system was updated. Since Volvo PV did not want to buy the software direct from CTH, the company RD&T Technology was formed which in turn owns the RD&T software.

Spillover to other industries

The research in both Geometry Assurance and IT Process has contributed to an increased use of simulation tools in a range of other industries besides the automotive industry, which was among the first to implement simulation systems.

Within Geometry Assurance, Swerea IVF's DDBS database tool has enabled spillover to subcontractors, including those outside the automotive industry and to such companies as Husqvarna, Ericsson and Sandvik. According to interview data, project support from VINNOVA has played a major role in enabling internal entrepreneurs to assert long-term development projects over short term efforts.

Impacts for R&D implementers

Universities becoming more attractive to industry

Companies understand the value of partnerships with universities and are seeking out existing competence instead of building up their own internally. Within Geometric Assurance, CTH plus Swerea IVF and FCC are good examples of the way researchers have focused on an area highly industry-relevant. Within IT Process, industry-relevant university research is being conducted chiefly at CTH, KTH, LTU and JTH. It is not merely doctoral students and senior researchers who are taken on by industry; thesis workers are also indirectly helping strengthen the role of universities as sources of knowledge. The importance of competence development is also illustrated in the questionnaires, with industry seeing it as the most important result of the participation. In the project manager questionnaire, new and deeper contacts with industry are the most important personal results of the participation.

Institutes serving as bridge-builders and disseminators of technology

In the projects within the five programmes relevant to IT, there are essentially only two participating institutes, Swerea IVF and FCC. Swerea IVF has a long history; however the five programmes brought much-needed continuity to sections of the operation during a very difficult period of major cutbacks at the start of the century. Thus, for Swerea IVF it is hardly a question of having built up a critical mass, more that the institute has managed to preserve its resources and, with MERA, perhaps even rebuild them. Initially formed in 2001, FCC has built up its operation during this century, but only to a small degree through the five programmes.

Institutes serve as bridge-builders; they find out what companies need and try to combine this with the needs of universities. Ideas for partnership projects emerge in dialogue with companies or through direct contacts when companies seek help from institutes to solve specific problems. This type of contact has also resulted in industrial doctoral studentships. Swerea IVF also serves as a disseminator of technology between industries, as the institute also cooperates with companies and universities outside the automotive industry. An example of this is the way the DDBS database tool aided the suppliers in adapting to the needs of the automotive industry. This has involved a spillover to such companies as the tool manufacturer LID Verktyg and its customers in other countries, as well as companies outside the automotive industry such as Husqvarna, Ericsson and Sandvik.

Internationally competitive R&D milieus

In the project manager questionnaire to universities and institutes, 70% of respondents stated that the groups' participation in international collaboration has increased since the time prior to participating in one of the five programmes. Of these, 63% said the projects they participated in were very important to the international partnerships. Those interviewed also had the impression that the programmes in question helped make their R&D milieus more internationally competitive and that they had become more in demand as partners for R&D milieus in other countries.

Background

Sweden has a long and proud history as an industrial nation and, after the Second World War, its industry grew even stronger. At that time, the manufacturing industry became a strong driver of social development but the Swedish government also took on greater responsibility for industrial development in general and technological development in particular. Higher education expanded, industrial research institutes were formed and research resources for the technical universities were enhanced. In addition, greatly increasing government investment through infrastructural products became a decisive part of the interaction between state and manufacturing industry.

Following the crisis of the 1970s, the manufacturing industry underwent a range of revolutionary structural changes. Many of these had already begun much earlier, but would now increase in strength during the 1980s, 1990s and 2000s due to something dubbed “the third industrial revolution”. The two greatest drivers behind this were *internationalisation* and the breakthrough of *information and communication technology (ICT)*. These multi-dimensional drivers have had far-reaching consequences for the manufacturing industry. Amongst other things, internationalisation has involved tougher global competition, increased concentration and altered production systems with greater degrees of specialisation and rationalisation. ICT has increased the pace of the above-mentioned internationalisation, but has also had dramatic consequences for production and job-sharing in society.

Although the manufacturing industry has gradually reduced in relative importance for Sweden (even as it continues to grow in terms of absolute turnover), in 2007 it accounted for just under 15% of GDP and barely 17% of the workforce. However, bearing in mind that the employment multiplier for the automotive industry has been estimated at 2.6 (one vacancy in the automotive industry leads to 1.6 vacancies in other industries) the importance of the manufacturing industry is far greater than that. At the same time, the manufacturing industry accounts for just over 55% of the total industrial R&D investment, which shows what is needed in order to maintain international competitiveness and how important the manufacturing industry is for Sweden’s industrially funded R&D. Only 6% or so of the manufacturing industry’s R&D is publicly funded, but this proportion is regarded by industry is very important since it allows (and often assumes) a kind of long-term thinking seldom possible with internal funding. This forms an important part of the background to the government’s investment in needs-driven R&D relevant to the manufacturing industry.

Programmes and definitions

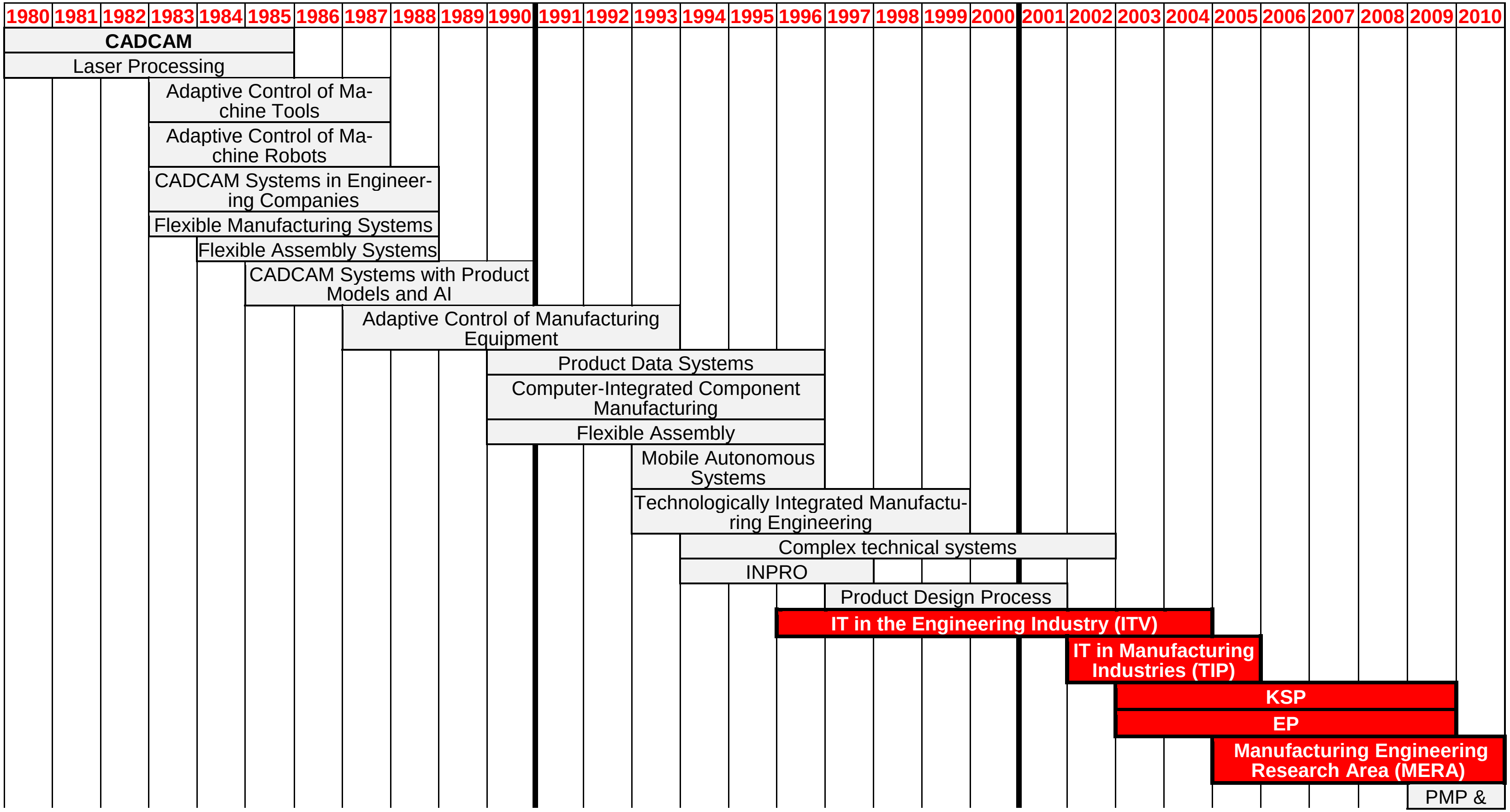
As shown in figure 7, over three decades VINNOVA and its forerunners Nutek and STU invested in a long list of R&D programmes relevant to the manufacturing industry within the range of different technological areas.

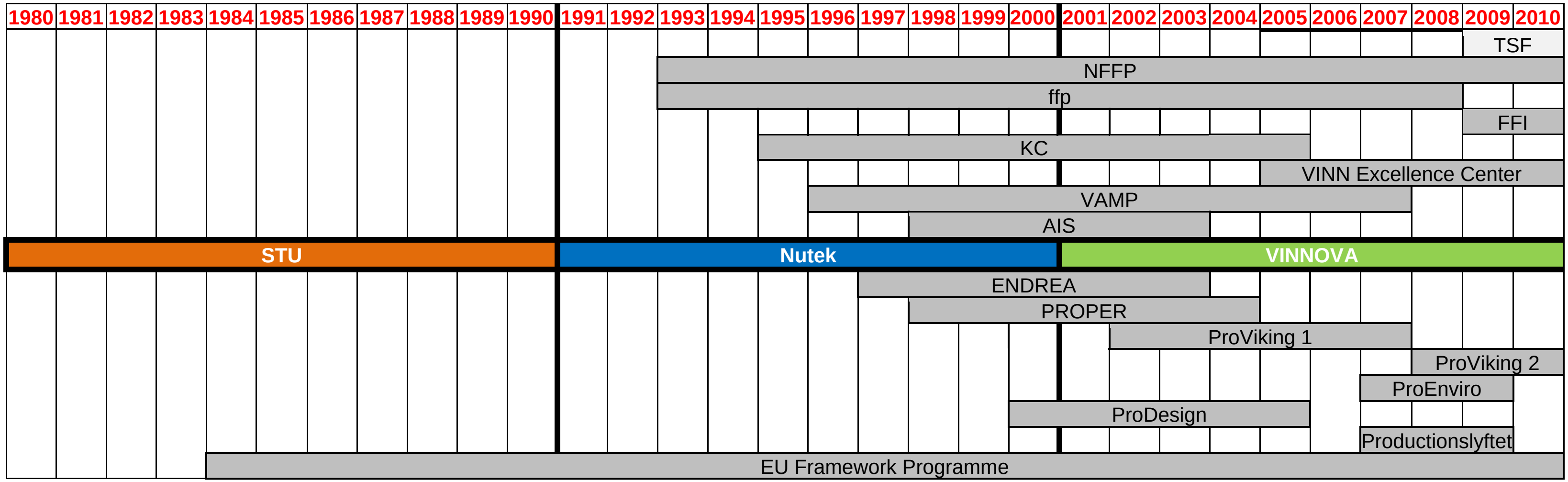
This impact analysis has also focused on five programmes which at the same time resulted in something of a time delimitation (1996-present):

- ITV (IT in the engineering industry, 1996–2004)
- TIP (Product development in the manufacturing industry, 2002–2005)
- KSP (Complex assembled products, 2003–2009)
- EP (Efficient product development, 2003–2009)
- MERA (Manufacturing Engineering Research Area, 2005–2010)

Despite this programme delimitation, there was an early realisation that it would also be essential to consider a number of other programmes; especially other VINNOVA programmes, SSF's ProViking programme and the EU Framework Programme, see Figure 7. For this reason, in working with the impact analysis, we have applied a kind of systems approach which takes into consideration the overall impacts of all financiers in the context of relevant R&D investment. This is known as the "5+ effort" and is illustrated in Figure 8.

Figure 7. Government R&D initiatives within the product manufacture area. The efforts depicted under the line "STU/Nutek/VINNOVA" are funded elsewhere.

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VINNOVA
ENDREA
PROPER
ProViking 1
ProViking 2
ProEnviro
ProDesign
Productionslyftet
EU Framework Programme

Figure 8. Illustration of 5+ effort in which the three blue ellipses on the left illustrate the various R&D efforts by VINNOVA and its forerunners and the bottom red ellipse the efforts of other financiers within the same areas.

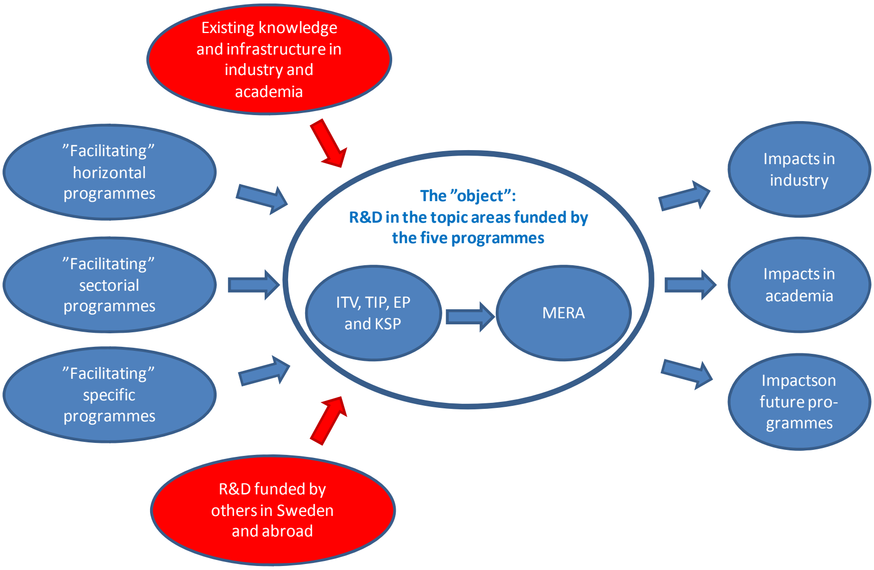


Figure 9 shows the five programmes' government subsidy (meaning that MERA is "above" the other programmes and not behind them).[6] we can clearly see from this figure at the distribution over time is extremely even and that VINNOVA's public funding within the area of product manufacture "exploded" once MERA came into full operation in 2006. It should be noted here that MERA was a fixed-term, government assignment.

[6] These details are based on grants made by Nutek and VINNOVA.

Figure 9. The five programmes' total government subsidies.

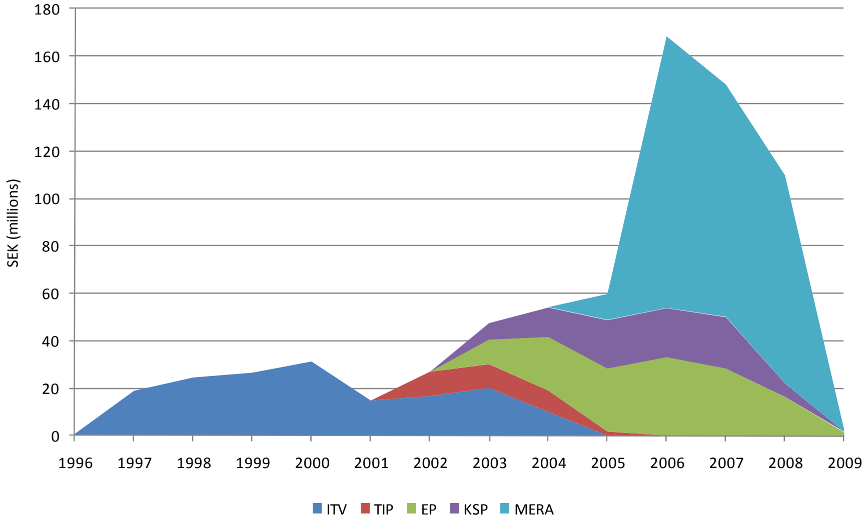


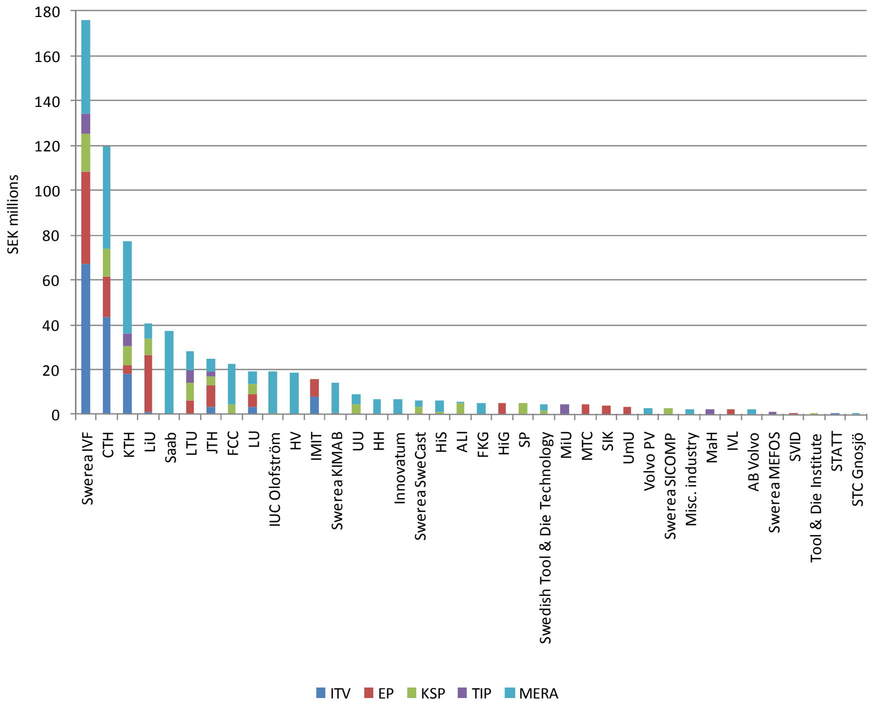
Table 3 shows a simple comparison between the five programmes. As is apparent, the programmes have differed greatly in terms of government budgets. However, it is worth bearing in mind that the actual extent of the programmes is about double the size shown in the table, since industry has invested at least as much as the State. The number of participating organisations also differs markedly, since the old programmes (ITV and TIP) are distinct from the more recent ones which show significantly broader participation. MERA is the only one of the five programmes which in some cases had companies amongst its beneficiaries.

Table 3. The number of projects, government budget and number of unique recipients of public funds in different categories for the five programmes. In this context, each participating university is counted as a recipient regardless of how many institutions took part. The summary of participants for each category has a considerable degree of "double counting" since many participants are involved in several programmes. Budgets are shown in SEK (millions).

			Number of recipients of public funds				
	No. projects	Public budget	Institutes	Univ	Companies	Other	Total
ITV	23	145	2	5	0	1	8
TIP	12	31	2	5	0	0	7
EP	35	139	5	8	0	2	15
KSP	19	88	6	8	0	3	17
MERA	56	304	5	10	5	4	24
Total	**145**	**707**	**20**	**36**	**5**	**10**	**71**

Figure 10 shows the distribution of the total government subsidies from the five programmes to recipients.[7] Swerea IVF is clearly the R&D implementer which has received by far the largest subsidy. Amongst other things, this can be explained by the fact that the five programmes have emphases which correspond very well with those of the institute. It may also be noted that CTH, KTH and LiU are major subsidy recipients. However, since each one of these educational establishments has several institutions in receipt of subsidies, any conclusions about concentrated efforts should be drawn with caution. It may be observed that 11 (Swedish) research institutes and 15 universities participated, which indicates a relatively good distribution across the country.

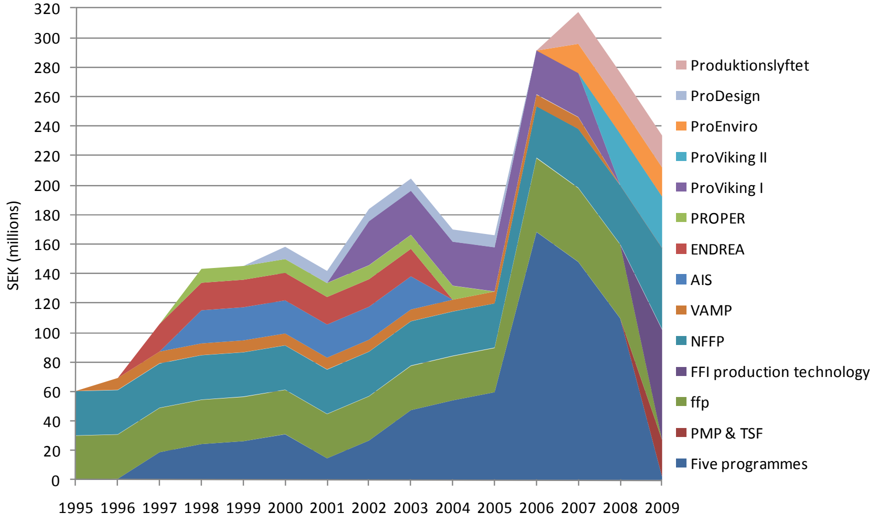
Figure 10. End recipients of government subsidies from the five programmes.



[7] These details are also based on grants made by Nutek and VINNOVA and take into consideration transfers of subsidies from project coordinators to other project partners.

Figure 11 clearly illustrates the need for a systems approach to R&D funding when assessing the impacts. Until MERA came into full operation in 2006, the five programmes did not constitute even half the government funding in the area, which clearly advocates major caution in attributing the substudies in the analysis. However, this figure does not provide the whole picture. On the one hand, the funding from the EU Framework Programme (which is of significant scope) is entirely absent; but unfortunately such information has not been gathered. On the other hand, it is not necessarily the case that all the funding shown in the figure is used for R&D within the product manufacture area, particularly within the "other programmes" (in other words those above the five programmes).

Figure 11. Total government subsidies from R&D programmes relevant to the manufacturing industry. For the sake of clarity, in this figure the five programmes have been merged into the dark blue at the bottom (see Figure 9). Please note that the order in the key is the same as in the figure (bottom to top).



Implementation

At the request of VINNOVA, this impact analysis was conducted in the period April 2009 - January 2010 by Faugert & Co Utvärdering AB. The data collection and analysis methods used were:

1. 14 exploratory interviews
2. Literature studies
3. Database studies:
   i. Industry databases from Statistics Sweden, Eurostat and OECD
   ii. VINNOVA’s project funding database
   iii. VINNOVA’s database of Swedish participation in EU Framework Programmes
   iv. VINNOVA’s Swedish industry database
   v. EUREKA’s project participation database
4. 40 in-depth interviews, mainly with project participants
5. Brief interviews
6. Questionnaires:
   i. Questionnaire to the five programmes’ participants within industry
   ii. Questionnaire to the five programmes’ project managers within universities and institutes
7. Reconstructed impact logics
8. Survey of human capital mobility
9. Survey of spin-off companies
10. Reference group and interpretation seminar

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