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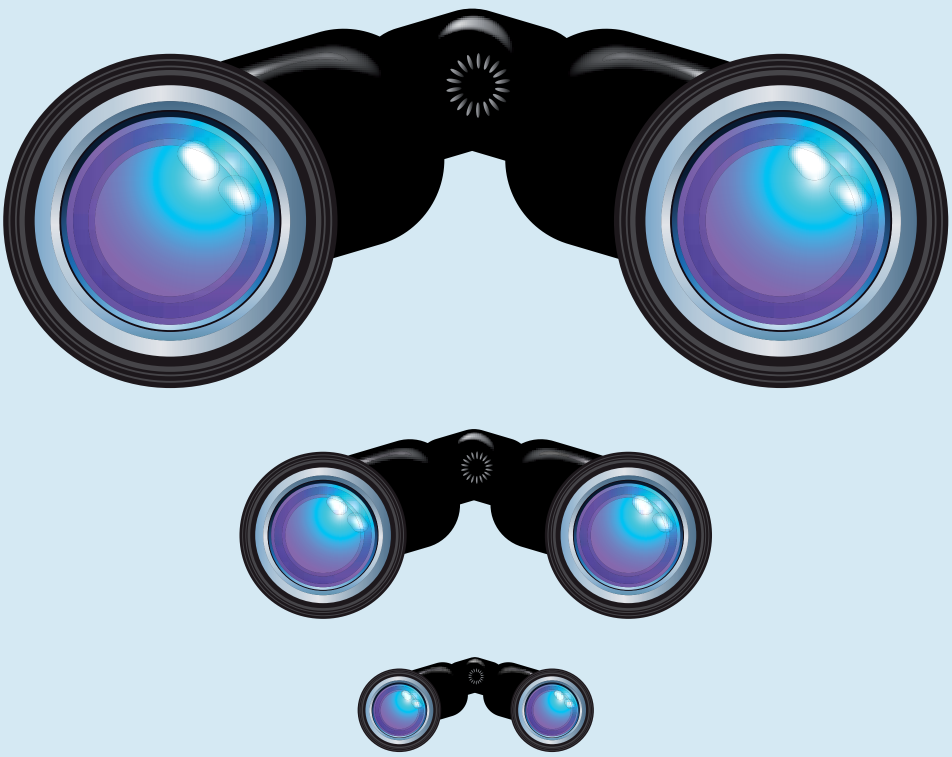
Innovations and new technology

- what is the role of research?
Implications for public policy

LENNART ELG - VINNOVA



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VINNOVA's vision is for Sweden to be a world-leading country in research and innovation, an attractive place in which to invest and conduct business. We promote collaborations between companies, universities, research institutes and the public sector. We do this by stimulating a greater use of research, by making long-term investment in strong research and innovation milieus and by developing catalytic meeting places. VINNOVA's activities also focus on strengthening international cooperation. In order to increase our impact, we are also dedicated to interacting with other research financiers and innovation-promoting organisations. Every year VINNOVA invests about SEK 2.7 billion in various initiatives.

VINNOVA is a Swedish government agency working under the Ministry of Enterprise, Energy and Communications and acts as the national contact agency for the EU Framework Programme for R&D. We are also the Swedish government's expert agency within the field of innovation policy. VINNOVA was founded in January 2001. About 200 people work here and we have offices in Stockholm and Brussels. Our Director General is Charlotte Brogren.

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Innovations and new technology

- what is the role of research? Implications for public policy

AUTHOR: LENNART ELG - VINNOVA

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Foreword

The ability to create and benefit from innovation plays a central role in income, employment and quality of life. Not only do innovations contribute to prosperity, they are increasingly important in addressing the many social challenges created by our quest for prosperity. This was emphasised in the Innovation Strategy adopted by OECD finance ministers in 2010.

Research-based competence plays an increasingly important role in the development of innovations and new technology. In developing effective innovation-oriented R&D policies, it is important to understand how, and under what conditions, research-based expertise can contribute to prosperity and address social challenges. The purpose of this report is to summarise 40 years of research into the links between innovation, technology and research.

The main message is that we need to think of innovation not as a sudden flash of inspiration, but as a long process of searching, experimenting and learning. Publicly funded research can contribute in many different ways and at all stages of the innovation process. For this to become a reality requires policies that allow for continuous interaction so that researchers and companies can learn from each other. We hope this publication may help stimulate innovation efforts through increased understanding of the long-term effects and the complex relationship between public investment in research and sustainable growth.

The author of this report, Lennart Elg, has spent the past 40 years analysing science, technology and innovation policy at VINNOVA and its predecessors. He has also served as an expert for OECD and the European Commission. This report is the result of a long learning process on the interaction between policy research and practice.

VINNOVA in April 2014

Charlotte Brogren
Director General

Göran Marklund
Deputy Director General

Summary

This report aims to give a brief summary of what we have learned about the ways in which research-based competence contributes to innovation and new technology. It also describes how the competence base of innovation can be strengthened by policy measures which support an interaction between business and research.

Innovation is the process by which new products, processes, methods or services are created. Innovation offers added value for end users by providing better and/or cheaper functionality than previous options. Innovation combines changes in technology, business models, organisation etc. The basic idea may be a new technical solution, a new business model or a change in organisation. More often than not, however, changes in all aspects are required in order to realise the full potential.

In a competitive economy, no business can survive long term without updating its products and services or the ways in which they are produced or delivered. Innovation policy must promote renewal across all business sectors and not just focus on high tech industries.

Since most innovations are complex and each subsystem has its own limitations, an important part of the innovation process is finding the right balance between conflicting demands. In most cases, there are several possible ways of providing a new function to users, or possible applications of a new technology. Which combination of features the market will prefer cannot be predicted with any certainty. The ultimate value of an innovation is also built through adaptation and improvement, often accumulated over decades. Whether the origin was a market opportunity or a new technological capability, innovation can best be thought of as an iterative, experimental search process.

Innovation integrates knowledge from a number of different fields: technology, market, design, economics etc. It is hard to collect all the necessary competences in a single organisation. The costs are high, competence quickly become outdated, and the company misses opportunities to learn from a broader set of experiences. Thus, innovation has become a process of constant interaction; with current or future customers, with suppliers and competitors, with consultants and with academic researchers.

“Innovation systems” is our way of summarising the patterns of interaction and mutual dependence we observe between businesses and public actors. The capacity to innovate depends on how well different parts of this system are adapted to each other and how well they work together.

Historically, new technology was developed on the basis of practical experience. A scientific understanding of how and why a technology works has often paved the way for later improvements, but was not always necessary for the original innovation. Today, the relationship between science and innovation is more complex and interdependent. Science-based technologies such as microelectronics or biotechnology could not have been developed without scientific understanding – but modern science is equally dependent on advanced technology.

Science-based competence plays an important role in industry's capacity to innovate, but there is no linear route from advanced research to innovation. Successful cooperation draws on the accumulated competence of academic researchers more often than it does on the exploitation of specific research results.

Innovation is a long search process before as well as after a new product or process is launched, rather than a sudden flash of inspiration. Research-based competence can help this search process in many ways, but the initial product idea is rarely the most important contribution. An important strategic role is helping identify long-term threats and opportunities; areas in which a company needs to invest in new competence.

The main goal of policies aimed at improving industry-university interaction should be to help the actors coordinate their strategic research agendas, rather than to "transfer research results". Direct interaction and dialogue between business and public research is a prerequisite for effective knowledge transfer. However, such a dialogue requires sufficient competence in industry to pick out potential partners and identify research questions. The purpose of such a dialogue cannot be limited to prioritising between issues already on the academic agenda; there must be mutual development of new research and development agendas. Cooperation must be built from the ground upwards; it cannot be planned from the top, but neither will it necessarily come about spontaneously. Policy can help or hinder such processes.

Innovation policy has traditionally focused on improving long-term competitiveness at national or regional level. In recent years, political attention has also been directed at using innovation to address societal challenges; environmental issues for example. Economists tend to prefer "technology-neutral" performance standards, but these risk favouring marginal improvements to existing technologies whilst discouraging more radical, long-term solutions.

With the increased globalisation of industry, support for research and development has become a policy tool to make countries or regions into attractive locations for investment. For Sweden, such a policy cannot aim at building a closed and more or less complete national innovation system. Our task is instead to determine which roles we can aspire to in globalised innovation systems.

Economists tend to think of innovation as a production process whereby knowledge is transformed into new products or processes. A more productive metaphor describes innovation as an experimental learning process in which organisations and individuals build new competence. This competence enhances their competitiveness with new products, processes or business models.

As there are no simple prescriptions for optimal policies, an ability to learn is also important in policy development. This means the ability to learn from others, taking into account differences of policy context. It also means the ability to learn from our own experiences, taking these into account as we develop new policy instruments. Programmes differ according to the characteristics of the knowledge field, actors involved, prospective users etc. Policy must take this into account and not try to apply a one-size-fits-all model.

1 A personal introduction

Requirements for a more innovative society include a competence base, entrepreneurs willing to take risks and develop new activities, and rules (institutions[1]) that support innovation. Change does not happen by itself; someone has to take the initiative. However, the context sets the parameters of what is possible and can provide more or less powerful incentives for change.

This report focuses on the first aspect - how the competence base for innovation can be enhanced by policies that contribute to effective interaction between business and research. This does not mean the conditions for entrepreneurship are less important; simply that they are beyond the scope of this report. Policy has an important role in facilitating interaction between public research and innovation, but the political rhetoric is often based on simplistic ideas about how these relationships work.

Throughout this report, I will try to make use of the term "research-based competence" rather than "science-based knowledge or "scientific information". "Science" implies the passive use of an existing body of knowledge, while "research" suggests an active process; I will argue that this active process is a better way of thinking about the relationship between industry and academic research. Secondly, "competence" implies more than merely having access to information. Its most important aspect is a capacity to make use of the tools and results of research in addressing real-world problems.

The issue of the relationship between innovation and research is not a new one. In 1975, when I was a young policy analyst at the Swedish Academy of Engineering Sciences, I was asked to do a literature search to find out if there were any research findings available on this topic. My report formed part of a public inquiry into the organisation of public sector support for research and development. This issue has followed me throughout my career at various government agencies in the innovation policy field.

At the time that report was commissioned, innovation research was in its infancy. It was possible to gain a reasonably quick overview of this field; the early pioneers were pleasantly surprised when an outsider wanted to listen to them. Thus I was able to meet and discuss with many of this field's founding fathers: Chris Freeman, Roy Rothwell, Dick Nelson, Nathan Rosenberg, and Jim Utterback. When I started working for the

[1] North (1987).

government in 1980, I was given the opportunity to start a programme which funded Swedish research into this field.

The main concern at the time was whether research and innovation were essentially different activities which should be supported in different ways, or whether it was important to deal with both aspects together since they were interdependent. We now know that the question was framed too simply. Research-based competence plays an important role in business innovation, but successful innovation requires knowledge, competence and initiative from many other sources as well. Moreover, there is no automatic way from outstanding research to innovation. A successful interaction depends on the specific circumstances of each case, and is usually more about taking advantage of the expertise of researchers than exploiting specific research results.

Throughout my career, I've been able to integrate new concepts from innovation research, policy issues and my experience of trying to translate policy into practice. This report is my attempt to summarise what we've learned about how research-based expertise can contribute to innovation and new technologies, and how these insights can influence the design of policies that promote innovation capacity.

Understanding this interaction is important both for the development of effective policies, and in legitimising such policies. The social sciences are not bounded by any fixed laws of nature; human activity is too complex for that. What it can give us is more or less fruitful metaphors; models of thinking which interpret a complex reality. Thus the contribution of innovation research is not simple recipes for success. Rather, it equips us with better tools for considering the ways in which innovation and research benefit each other. This is the theme of this report.

In Chapter 2, "Innovation – a process of searching, experimenting and learning", I attempt to summarise what we've learned about how new products, processes and services are created, how firms build competence for this and what information sources they use.

In Chapter 3 "The role of research in innovation", I discuss what we've learned about the roles of research-based competence in innovation processes.

In Chapter 4, "Cooperation with academic research", we look in more depth at the ways in which publicly funded research can contribute to that process.

In Chapter 5, "The need for innovation policy", I discuss the rationale for innovation policy in order to build a competence base for future innovations.

In Chapter 6 "Lessons for an innovation-oriented R&D policy," we try to draw practical lessons on how effective policies should be formulated.

Chapter 7 “Conclusions”, sums up the main lessons I have learned from writing this report.

This report may be read in conjunction with “Impacts of Innovation Policy” (VINNOVA VA2012: 01) in which Staffan Håkansson and I discuss some of the same questions, based on a meta-analysis of a number of impact studies of R&D programmes at VINNOVA and its predecessors.

I would like to thank my former colleagues at VINNOVA, as well as professors Staffan Jacobsson, Staffan Laestadius, Åsa Lindholm-Dahlstrand and Dr. Eugenia Perez Vico, for their valuable comments during the work.

This is a revised version of a report originally published in Swedish in 2013. This revision has also been enhanced by comments received after publication of the Swedish version. Moreover the process of translating the text into English has, in itself, encouraged me to clarify some points. I would like to express my gratitude to Dr John Barber, former chair of the OECD Committee on Science and Technology Policy, for valuable comments on this version of the report.

2 Innovation – a process of searching, experimenting and learning

Innovation:

"The introduction or implementation of a new or significantly improved product, service or process, new marketing methods or new ways of organising business, work organisation or external relations."

(OECD, Oslo Manual for the measurement and comparison of innovation in business)

Observed from a comfortable distance, and with the benefit of hindsight, innovations can give the illusion of sudden flashes of inspiration, defining moments which transform the economy, almost overnight. For a long time, economists treated the appearance of innovations and new technologies as exogenous "acts of God" which, whilst certainly having an impact on the economy, could not be explained by economic analysis.

As innovations and new technology have emerged as the primary driving force of economic development, viewing them as inexplicable "acts of God" gives little guidance to policymakers concerned with the performance of the economy. I will attempt to argue that, taking a closer look, innovation is best viewed as a process over time characterised by searching, experimenting and learning.

Searching: for better ways of doing worthwhile things. Experimenting: because we can't see in advance the best way of accomplishing a desired outcome (or indeed what users really want or need). Learning: because actors involved in an innovation process will learn from it. The kind of learning which changes their ability to tackle future challenges and opportunities.

A closer study of these processes of searching, experimenting and learning can help us identify various ways in which public policy can help or hinder them. While inspiration certainly plays an important role, it tends to come to those who are prepared, and as Thomas Edison reminds us, innovation is "1% inspiration and 99% perspiration".

Innovation refers to the process of developing a new product, process, method or service that provides value-added to its users, by providing a function that is better and/or cheaper than previous options. The concept of innovation is also used for the outcome of a process, but I will argue that process should be the focus of policy.

Economists often think of innovation as a production process, where knowledge is transformed into a new product that takes the world by surprise. We measure R&D investment, relating these to outcomes in the form of patents, new products, GDP growth and so on. Then we congratulate ourselves on high levels of R&D investment, or worry about a European "research paradox".

However, this metaphor is problematic in several ways. A more productive mental model may be to think of innovation as a form of learning – for organisations and on an individual level.

Professor Richard Nelson, probably the world's leading expert on innovation from an economic perspective defines innovation as:

> *"The processes by which firms master product designs and production processes that are new to them, if not to the world, nation or sector."*

Note that Nelson's definition focuses on processes whereby companies learn something new and not on the results; new products or processes.

An idea or invention becomes an innovation only if the added value means it actually gets put into practical use. This is often described as "reaching the market", but innovations are also created and used internally, within firms and in the public sector.

The meaning of "new" in this context is not set in stone. An innovation may be new to the world, new to a particular branch of industry, etc. The problems in putting an innovation to use are similar because an innovation can rarely be used without modification; of both the innovation and the milieu of its use. The bulk of the value is also created in this adaptation process. Most innovations are therefore improvements and adaptations of earlier innovations.

2.1 Not just high tech

Innovations are not just new technological products or processes. The OECD definition of innovation also mentions organisational innovations, new distribution channels, new business models, etc. In fact, it is often misleading to think about technical or organisational innovation as separate processes. Most innovations combine changes in technology, business models, organisation, etc. The basic idea can be a new technological solution, a new business model or a new way of organising your business, but innovation usually requires changes in all respects.

IKEA is usually described as a new business model and the products do not look very high tech. However, behind IKEA's success are also advanced logistics, IT systems and so on. Similarly, new technology often requires changes in an organisation and its business models, and the like, in order to realise their full potential. The American economic historian Paul David has pointed out that it took 40 years before one could see the impact of electric power in American industrial productivity. It required major changes in the way production was organised before industry took full advantage of the new technology[2].

Innovation is not something that just happens in "high-tech industries." In a competitive economy, no company can survive in the long run without renewing its products and services – or the means to produce and deliver them. What we call low or medium technology continues to account for a large proportion of both manufacturing and service production. Over 90% of GDP in EU countries created in the activities of the OECD was classed as emanating from low or medium-high technologies.[3]

Production in the "high-tech industries" is often an input to other industries - but there is no passive transfer. Taking advantage of the opportunities that, say, information and communication technology offers require substantial investment in innovation. Companies in industries classed as low-or medium-tech make extensive use of R&D results and codified knowledge, but in ways that are often not recorded as research and development in national statistics.

Economic development cannot be driven solely by the small sector classified as "high technology". Innovation policy must promote innovation in all industries, not just focus on high technology. The OECD definition of high technology is also problematic as a basis for drawing far-reaching policy conclusions. The definition classified a number of industries (at a high aggregation level) as "high-tech" in the early 1990s, based on how much the industry invested globally in R&D at that time, relative to its value added.

The definition does not capture differences between companies in the same industry. A subcontractor in Vietnam engaged in simple assembly of electronic components is classified as high technology even if it does not conduct any research and development at all. Meanwhile, the world's most advanced steel plants and paper mills can never be classified as high-tech, because of their complementary need for high levels of investment in fixed capital, and aerospace manufacture is classified as medium tech.

[2] David (1990).
[3] Hirsch-Kreinsen et al (2005).

The standard definition of 'high tech' measures R&D intensity not the generation or use of advanced technology as such. A far better measure is the proportion of scientists, engineers and highly qualified technicians in the labour force.

2.2 Not just applied science

After World War II, economists were optimistic about the economy's ability to quickly assimilate new knowledge and imitate new technologies. Empirical research has shown this optimism to be unwarranted. The differences between countries in economic development are much greater today than they were before the Industrial Revolution[4]. Developing countries experience significant difficulty catching up with the most advanced countries[5]. One reason for this is that even science-based innovation is not just an application of a scientific principle.

Published research requires advanced knowledge in order to be interpreted. Using it requires in-depth understanding of the local context in which the knowledge will be applied, as well as access to a broad range of complementary competences. Research results are not recipes which state how to apply a piece of knowledge in real life; they indicate how one might go about doing something useful.

The creation of a marketable product or service based on interesting research results poses a range of questions:

- Is it possible to make the proposed solution work in practice, away from a carefully controlled laboratory milieu?
- What is needed to make it work in terms of equipment, support systems, quality of input and services, etc?
- Is the proposed product/service safe? No unpleasant side effects?
- Is it cost-effective compared to existing alternatives (or is there a reasonable chance of it becoming so)?
- Why would anyone be willing to buy this instead of existing alternatives? How can we convince them?

To answer all these questions, we need to combine knowledge from a variety of sources: technology and marketing, design, finance and so on. The technical content usually integrates a variety of technologies. Each technology can draw on a variety of sources, including engineering design and development, learning by doing and new software. Of increasing importance are technologies such as computer-aided design and simulation

[4] Landes (1998).
[5] See e.g. Denison (1967), Fagerberg (1994), Fagerberg et al (2011).

which enhance the engineering process[6]. A particular technology may also need to incorporate knowledge from several different fields of research.

As Nathan Rosenberg has noted, the technical problems we solve are just a fraction of those we could attempt. Which ones we choose to address is governed more by technical/market needs and problems than by the latest scientific findings.[7] Moreover, an innovation does not come to the market as an idea; it is incorporated into a product, in which the company has had to make trade-offs between differing (and sometimes conflicting) demands. Such demands arise from a range of potential users; from different application areas and different stages of the manufacturing process.

Success comes from striking the right balance between conflicting requirements and making subsystems function well together. The "correct" balance cannot be calculated on any scientific basis. Metcalfe[8] notes that such knowledge can only be gained in context of a competitive market process. Innovation is a means of gaining competitive advantage but, at the same time, competition shapes the innovation process.

Even the simplest innovation, a Neolithic stone axe from 5000 BC, proves surprisingly complex. It utilises the property of certain rocks which shatter to form sharp edges; the momentum of a piece of sharpened rock is then converted into force when the downward stroke hits its target and so on. It took skill to use it effectively and experience to find the right type of stone and then process it. The stone axe is perhaps the oldest example of Adam Smith's division of labour. Archaeologists have found large accumulations of stone axes being manufactured, far from where the mineral occurred naturally. This means that, thousands of years ago, someone specialised in manufacturing axes, a skill which they exchanged for other necessities. Furthermore, they were prepared to search far and wide to find the right material (or it may mean that another group became merchants and specialised in providing the coveted raw material.)

2.3 Innovation in constant interaction – innovation systems

One of the most robust results from innovation research is that innovation is not something that happens within the four walls of a company. It happens in constant interaction with the outside world: customers, suppliers, research institutions and so on.

The need to combine expertise in many different areas (and with constant renewal of the competence base) makes it difficult to gather all the necessary competences in one organisation. This would be expensive as competences quickly become obsolete and so opportunities to learn from others' experiences are lost.

[6] Dodgson et al (2005).
[7] Rosenberg (1969).
[8] Metcalfe (2005).

For this reason, innovation typically takes place in an interaction with: existing or prospective customers; suppliers of inputs, components or sub-systems; competing firms, consultancies and public research institutions.

In an interaction like this, a company must constantly strike a balance between continuity and change. Continuity is important as it takes time and money to identify and evaluate potential partners and build trust with them. Still, one must always be prepared to change partners as competence needs are constantly evolving.

Different analysts have used different terms for this interaction: Development blocks, networks, clusters, innovation systems, open innovation and so on. These concepts come from different research traditions and emphasise different aspects of the interaction. Nevertheless, their common core is the fact that development or innovation is something which happens in an interaction between firms and their milieus.

"Innovation systems" is a way of summarising the patterns of interactions and interdependencies we can see evolving and changing between companies, as well as between public-sector organisations. This doesn't mean innovation systems have been deliberately designed – or even that this would be possible. Such patterns of collaboration and dependency have evolved over long periods as the result of many small decisions by different actors. We should not (as is sometimes seen in the political debate) make the mistake of describing the innovation system as "institutions to support R&D and help startups over their initial funding difficulties."[9] The key actors in any innovation system are the companies themselves and their skilled staff. The only locus where all knowledge inputs can be weighed and combined consists of firms engaged in competition[10]. However, firms would struggle to innovate on their own, without interaction with a nurturing environment of both private and public supporting actors and institutions for example higher education, consultants, standards bodies, capital markets et cetera.

Research into innovation systems

Policy research into innovation systems was originally developed (in the late 1980s) as a response to the question of why industrialised countries were converging in economic development despite different sets of institutions, such as:

- U.S. Venture capital, startups, mobile labour force
- Japan: Large firms, lifelong employment, major ownership conglomerates (*keiretsu*).
- Germany: strong SME, apprenticeship and bank financing rather than venture capital.

[9] Braunerhielm et al (2012).
[10] Metcalfe (2005).

The answer that emerged from this research was that innovation/development capacity was affected by a number of factors/institutional relationships and so on which supported or offset each other: the innovation system. Its performance relies on all parts of the innovation system functioning and interacting positively. This is also affected by the rules ("institutions") set by society and the actors themselves.

From this standpoint, there is no "best" model for organising social institutions. What matters is that different parts of the innovation system are well adapted to each other and open to collaboration. The emphasis is not on improved performance for one particular factor. Excellent public research is not enough if companies lack the ability to exploit this competence, or if researchers lack the motivation to interact with the outside world.

"Innovation systems" is not a label on policymakers' toolboxes, however companies are affected by social institutions, both in the sense of rules and in the organisation and governance of public actors such as universities or institutes.

An important lesson has been that it is not enough to think of "a national innovation system." Even within a specific country, the innovation processes and internal systems it develops will differ substantially; between sectors, innovation lifecycle phases and so on. This is something policy makers must understand and take into account, and needs us to be familiar with the circumstances in different sectors. Furthermore, innovation systems are not bounded by national borders. Primarily, it is the "rules of the game" that are defined nationally. Rules for knowledge creation and entrepreneurship, how public R&D institutions are organised and so on. [11]

Innovation system research does not claim to explain *why* innovations appear. Its focus is on understanding the context in which innovators and entrepreneurs can choose to act. It has been developed at the intersection of institutional and evolutionary economics. Institutional economists emphasise the fact that an economy does not merely consist of atomistic firms and the invisible hand of the market. Companies and other actors interact and the society's rules also play an important role. Evolutionary economists assume that the economy is constantly changing in ways that cannot be described as temporary deviations from a stable equilibrium.

Research into innovation systems was developed in close cooperation with policy development. Several of the leading researchers, including Christopher Freeman and Richard Nelson had close contacts with policy thinkers at OECD, and Bengt Åke Lundvall was for some years head of the OECD Directorate for Science, Technology and Industry,

[11] For the sake of simplicity, I will sometimes refer to "the Swedish (or national) innovation system" in the singular. This should be interpreted as that part of a relevant sectoral innovation system which can be influenced by national policy.

which analyses member countries' innovation policies, using the innovation system toolbox.

2.4 Often a long process

New technologies - and innovations - do not arise out of nowhere as flashes of genius. They are based on finding new ways of combining existing building blocks[12] (see Schumpeter's definition of innovation as "new combinations"!).

The further away from existing technology we find building blocks to combine, the more radical we consider the innovation which they form. The jet engine, for example, has nothing in common with the piston engine other than its purpose. Its development cannot be explained as a gradual improvement of the piston engine. However, the jet engine "inherited" existing technologies from other fields of application, including the steam turbine[13].

An innovation may often remain "up in the air" for a long time as a concept of what should be possible to achieve. Einstein described the scientific principles behind the laser more than 60 years before its first application. The competences needed to realise an innovation is far more complex than the scientific foundations of its basic principle.

The time from patented invention to a useful product may also be long (see Table 1).

Table 1 A long time from invention to commercial product

	INVENTION	PRODUCT	YEARS
DIGITAL COMPUTER	1939	1943	4
FLOAT GLASS PROCESS	1902	1943	41
FLUORESCENT LIGHTING	1901	1938	37
HELICOPTER	1904	1936	32
JET ENGINE	1928	1941	13
TAPE RECORDER	1898	1937	39
RADAR	1925	1934	9
RADIO	1900	1918	18
SYNTHETIC DETERGENTS	1886	1928	42
TELEVISION	1923	1936	13
TRANSISTOR	1948	1950	2
ZIPPER	1891	1923	32

Source: Clark, Freeman & Soete (1981)

[12] Arthur (2009).
[13] The first Swedish jet engines were developed by Stal Laval. It had a long experience in building steam turbines for power generation, but no prior experience with piston-powered aircraft engines. In a similar development, General Electric became a major supplier of jet engines in the US.

Starting in the early 1920s, a number of inventors and companies experimented with the jet engine as an idea. This was before Frank Whittle was awarded a patent for his turbojet engine in 1928 and the first practical use of the jet engine came only at the end of World War II. This long search process also explains why history is full of "parallel" inventions. Alexander Graham Bell was not alone in experimenting with voice transmission, but we only remember the one who was first to the patent office, or had commercial success.

As we will discuss later, the first useful product is still only the first tentative step in a long process of development and diffusion.

2.5 An experimental search process

Whether it is triggered by a market opportunity or a technical possibility, the innovation process is best described as an iterative search process. There are usually several possible ways of delivering a new feature to the customer, or potential areas of application for a new technology. The company (and its partners) cannot test them all; they must focus on one or a few alternatives. Which alternatives are chosen is guided partly by rational choice, where different options are tested against each other. However, which options are initially chosen is also governed by the competence the company has accumulated through past experience and existing network relationships.

Since innovations are generally complex with each component or subsystem having its own limitations, much of the innovation process is about finding the right balance between conflicting requirements. It is not possible to predict in advance which combination of properties the market will prefer. This is not just a matter of preferences (which can be difficult for the client to articulate without prior experience); the optimal choice may also depend on how other customers are acting in regard to, say, the choice between competing standards. Which operating system other clients choose when buying a mobile phone affects how many "apps" will be developed; this in turn will affect what I can do with my own mobile phone, and so on.

2.6 Innovations are not born fully formed

As seen in the previous section, innovation combines knowledge from many different sources, some of which can only be acquired through practical use of early versions of the innovation. This means the innovation process is incomplete when the first product or service is put to use. The first Macintosh computer in 1984 defined the user interface of the modern personal computer, with the menu-based, graphical user interface and mouse[14]. At the same time it had 128 KB of internal memory and no hard drive. The first innovation in a new field sows a seed which, given the right milieu and interaction with the outside world, may sometimes grow into something significant. The ultimate significance of an innovation depends largely on how well this interaction develops.[15]

An important source of knowledge in this interaction is experiences and requests from early users. New requirements and opportunities are discovered when the innovation is put to use. Early use often provides ideas for additional applications, which in turn requires the innovation to be adapted to changed conditions.

It is these accumulated changes and improvements, often over several decades, which create the long-term value of an innovation. An innovation often stimulates other innovations. Competitors are forced to improve their products and a technology developed in one context may find applications in others.

It is not always the original innovator who ultimately draws the longest straw. Being first to innovate can be important in building a market share and thus affecting the standards that are set. However, it is the ability to consistently identify and realise needs and opportunities that creates winners. Sony introduced its Betamax video cassette recorder in 1975 and the competing VHS standard was introduced in 1976. According to many analysts Betamax provided better image quality, but could only record for an hour. VHS could provide 2-4 hours; enough to record an entire feature film. Video rental stores chose VHS and it became the dominant standard until it was replaced by the DVD. Of course Sony realised its mistake and extended the capacity of Betamax; but it was too late, the market was already locked into VHS.

Early versions of an innovation often have to make do with available off-the-shelf components or materials, originally developed for other purposes. Once market requirements begin to stabilise into a dominant design, it becomes possible to streamline performance and economy by optimising materials, components and so on, usually in collaboration with suppliers. New technologies can gradually improve the price/performance of the original innovation by replacing subsystems[16].

2.7 Open and closed technologies

When the number of building blocks (in the form of available technologies) increases, the number of possible combinations will also increase exponentially, although far from all combinations will be meaningful. As products become more complex, the number of

[14] Neither the mouse nor the graphic user interface were the result of any basic research at Apple. Both had been developed at Xerox PARC laboratory, but Xerox failed to see their significance. They were copied by Apple initially in their Lisa II model, which was a commercial failure.
[15] Rosenberg (1982).
[16] Abernathy & Utterback (1978).

technologies combined in a single product increases and thus the number of competences needed to develop, manufacture and distribute them[17].

Meanwhile, the character of available technologies has changed. A technology such as the Bessemer process made one thing: steel, essentially in a special facility. Modern, science-based "general purpose technologies", such as information and communication technology, molecular biology or nanotechnology, provide functions/building blocks that can be combined in many different contexts. This is not in itself a new phenomenon: Such technologies as steam power and mechanical engineering were horizontal technologies in the first wave of industrialisation, as were electrical power and chemicals in the late 19th and early 20th centuries. What has changed is the breadth and scope of such technologies.

2.8 Are small firms more creative?

One of the first issues addressed by innovation research was whether large or small firms were more innovative. Eventually, the discussion refocused onto the performance of new versus established businesses and not firm size itself.

The role of new, entrepreneurial firms seems particularly important to the early exploration of a new generic technology's possibilities[18]. In cases where large companies have managed to create more radical innovations, we can often identify internal entrepreneurs who played a major role. Ericsson's development of mobile telephony started in a small development company called Svenska Radio Aktiebolaget (SRA); SRA was then acquired by Ericsson and, later on, renamed Ericsson Radio Systems (ERA). Work could proceed at a safe distance from the main Ericsson office, which was preoccupied with becoming a player in the early personal computer market[19]. Astra's Losec – for a while the world's best-selling drug – was developed by a small team at Hässle, a subsidiary at safe distance from headquarters. The success came about despite active resistance from Astra's scientific advisory board which on several occasions recommended cancelling the project. In both cases, public R&D support also played a small but important role in keeping these projects alive until top management decided to invest in them.

Large firms seem to have the advantage once market preferences become clearer and resources can be focused on streamlining production and gaining market share. Henderson & Clark relate this to the issue of whether the necessary competences are

[17] Oskarsson (1993).
[18] Abernathy & Utterback (1978), Eliasson (1993).
[19] See Arnold et al (2008), also discussed in sections 5.4 and 6.4 of this report.

consistent with existing corporate competence (especially the organisational competence embedded in established contact patterns, etc.) [20].

The division in roles between large, established firms and new, entrepreneurial startups also varies between industries. In information services, a company like Google can grow into a global company in a few years and replace established competitors. In the pharmaceutical industry, on the other hand, new bio-based companies evolve into specialised partners of established "big pharma" rather than replacing them.

Another early issue was the sources of innovation. Is market demand or new technological opportunities the main driver of innovation?

Today, research on innovation agrees that most innovation projects start with someone identifying a need, whereupon the search begins for ways to meet that need. Radical innovations are more likely to originate in new technological and scientific possibilities - but as we will see later the bulk of the value is created when the original innovation is elaborated and adapted to different needs. But identifying a need is not enough. To create an innovation, we must also find a way to meet the need - the world is full of needs that are waiting for their solution.

Most empirical studies show that firstly a company's customers and secondly its suppliers are the main innovation partners. Connections with public research play an important role in some industries; a role that is increasing in importance. However, customers and suppliers dominate when it comes to the number of contacts. As we will see, research-based competence is playing an increasingly important role but it is a mistake to focus primarily on research as a source of product ideas. Some inventions have been created ahead of any identified need (e.g. the laser[21]) but these are rare exceptions, not the general rule.

2.9 Value often accrues to the users of new technology

To realise its potential, research-based expertise needs to be combined with both the other competences plus entrepreneurship. Bhidé[22] argues that the US should not be overly concerned that countries like China are investing heavily in basic research. Competitiveness is built by capturing advanced knowledge from R&D and combining it with other, often "silent", competences in customer preferences and the like. Bhidé argues that such knowledge of user needs and preferences (as well as on the context in which that knowledge will be applied) is often much more locally based and elusive than new research. However, this does not mean that research-based competence is

[20] Henderson & Clark (1990).
[21] The device, not just the principle.
[22] Bhidé (2005).

unimportant. These skills are equally important in capturing the opportunities provided by new research results.

When the opportunities of microelectronics started to become apparent in the early 1980s, most countries considered it strategically important to build up a domestic component and computer industry. This was the goal of the Swedish National Microelectronics Programme (see Section 6.4) and many similar programmes in other countries. However, these programmes severely underestimated the economies of scale in microelectronics production, and today a few mega-factories (or "fabs") supply the world's needs for standard components. Moreover, Sweden did not become a major exporter of personal computers. Instead, the National Microelectronics Programme helped Ericsson become a competent customer for the microelectronic components it needed and thus lead the way in mobile telecommunication systems.

Some not so basic concepts

Since 1963, OECD has collected information on member countries' spending on research and development. For this purpose, OECD established a set of definitions which have come to play a core role in the policy debate of most industrial countries.

The OECD Frascati Manual classifies research into three categories:

- Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge about observable phenomena and facts, not directed toward any particular use.
- Applied research is original investigation to acquire new knowledge directed primarily towards a specific practical aim or objective.
- Experimental development is systematic effort, based on existing knowledge from research or practical experience, directed toward creating novel or improved materials, products, devices, processes, systems, or services.

As it became obvious that innovation involves more that formal research and development, OECD also developed measures of overall expenditures on innovation (the Oslo Manual):

- An innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations.

To give the reader a rough picture of the resources involved, Statistics Sweden reports total performance of R&D for 2012 as follows:

PERFORMING SECTOR	MSEK	PER CENT
BUSINESS ENTERPRISE SECTOR	81 903	68 %
UNIVERSITIES	32 787	27 %
PUBLIC SECTOR	5 807	5 %
PRIVATE NON-PROFIT	354	

Current Swedish statistics make no distinction research and development in the business sector. Earlier statistics provide an estimate of 10-15% of these expenditures being allocated to research.

A separate survey estimates total expenditures for innovation in the business sector for 2012 to be 161 820 MSEK, or about twice their investment in research and development.

Other industrial counties show similar patterns. Differences are mainly in the size of business sector R&D compared to public research, and the division of labour between universities and other public sector research institutions.

There are a number of problems in applying these distinctions in practise, and a recurring theme of this report is that research, development and innovation processes interact in complex ways and all depend on each other.

While we can assume that development and innovation mainly is the domain of business enterprises, and that universities mainly do research, usually without a particular use in mind, there is no clearcut mapping of the categories on the various actors. Companies do invest in research, and when this is done to explore and build competence in a field ahead of any particular use it fits the Frascati definition of "basic" research, even though companies may be wary of describing it as such.

Whether a research effort should be seen as "basic" or "applied" can vary depending on whether we ask the researchers involved or the agent funding the research. Bell Laboratories, an industrial research lab, have famously produced more Nobel Prize winners than many medium-sized nations, and while its staff enjoyed considerable freedom to pursue new knowledge without a particular use in mind, Bell Telephone no doubt expected to benefit from its investment.

As we will see in this report, a major contribution of academic researchers to industry is as consultants and discussion partners, rather than as a source of specific research results.

Industrial development and innovation can also not easily be delineated from the day-to-day operations of the firm. The way R&D expenditures are measured assumes that this is an activity which takes place separate from normal operations. This mainly applied to to large, massproducing manufacturing firms of the 20th century. Drawing the line is much harder for small firms, service production, or firms manufacturing complex systems adapted to each specific client.

3 The role of research in innovation and new technology

The previous chapter noted that innovation needs to combine competences from many different sources. Research-based competence is an important part of this, but is not sufficient as the sole basis for innovation. In this chapter we will look more closely at the ways in which research can contribute.

Studies of the role of research in innovation and change is not new, see Alfred North Whitehead's "Science and the Modern World" (1925), or Robert Merton's "Science, Technology and Society in Seventeenth Century England" (1938) 23. The authors of these studies emphasise that the relationship between scientific discovery and application is a complex interaction which cannot be simplified into a one-way information flow.

Historically, new technology first developed based on practical experience. Once the technology had seen its first use, a scientific understanding of "how" and "why" the technology works was able to help refine it beyond what was possible by blind experimentation. For example, Carnot formulated the principles of thermodynamics when he tried to improve the efficiency of contemporary steam engines.

Today the relationship between research and innovation is far more complex. Science-based technologies such as microelectronics and biotechnology could not have developed without scientific understanding. However, neither could modern science have evolved without modern technology in the form of ever more sophisticated instruments. Moreover, the extreme performance requirements of such instruments can, in turn, drive further technological developments.

This tight linkage becomes especially clear in technical research, which often alternates between building model systems in the laboratory, donning the engineer's hat, and then (in the research role) studying the properties of the system.

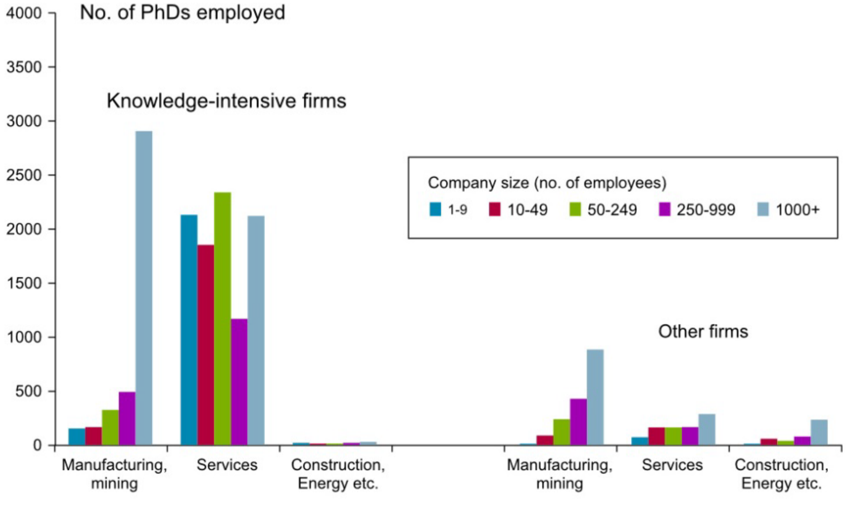
3.1 Human resources

In discussing the contribution of universities to innovation we often skim over the fundamental role of education and training. Traditionally, this has been discussed as the

[23] See also Schmookler (1950), Musson o. Robinson (1969).

need to keep undergraduate education "connected to research" in order to keep its content up to date. However, most postgraduates today are also employed outside the academic system. In Sweden, 58% of professionals with postgraduate education in engineering science are employed in the private sector, with a further 10% in state-owned enterprises. Only 21% were employed by academic institutions24. Not only does a higher proportion of graduates and postgraduates in industry provide a brain gain when these people are hired, it is also a prerequisite for other forms of active collaboration between companies and academic research. If we take this role seriously, it is not enough for a few students to reach the highest levels of academic excellence; it is equally as important for there to be enough people throughout the system with academic competences.

Figure 1. PhDs employed in industry (2009) by company size, knowledge intensity[25]



Source: VINNOVA (2011)

Not unexpectedly, we find postgraduates, mainly in knowledge-intensive firms. Among manufacturing companies postgraduates are concentrated in the largest firms. In the main however (about 70%), we find postgraduates in knowledge intensive services of all sizes: IT consulting, business services, R&D contractors and so on. Note that figure 1 includes all PhDs in industry, regardless of field. The distribution of qualified staff at

[24] Högskoleverket (2012). Statistics refer to 2007. The same observation applies, although not quite as strongly, to other fields than engineering. Here, 32% of PhDs remain in academia.
[25] Knowledge intensive firms are defined here as firms in which at least 30% of employees have at least three years of post-secondary education.

graduate level is remarkably similar, with about 6-7 graduates to each PhD. Knowledge intensive business services play an important role as competence nodes in the innovation system[26].

3.2 No linear "innovation chain"

A recurring concept in the policy debate is the "innovation chain", a notion that "free"/"investigator-driven"/etc. basic research of any kind automatically leads to innovation and prosperity:

> "Basic Research *> Applied Research > Development > Production > Market"*

It is of course difficult to apply research findings that do not yet exist, or distribute products that are not yet manufactured. However, as discussed above, research into innovation processes shows that this conceptual model gives a poor description of the relationship between research and innovation, in a number of ways:

- Most innovation processes start from a market idea[27]. A small section originate in a new technological opportunity, and an even smaller proportion is based on new research.
- An innovation is not just application of a scientific principle. It combines knowledge from many different sources and the difficulty lies in combining these competences and striking the right balance between conflicting requirements of the product.
- Research contributes to the innovation process in many ways but product ideas are not the most important contribution.
- Science and technology are interdependent. The direction of research is often determined by what instruments technology can offer. An important role of science is also to explain how and why existing technologies work (which can in turn indicate how they could be improved).
- Practical problems sometimes lead to fundamental insights. In 1964, Penzias and Wilson were looking for sources of interference to radio communications at Bell Laboratories (an industrial laboratory) when they discovered cosmic background radiation. This discovery changed our whole view of the universe. For this, they were awarded the Nobel Prize in Physics in 1978.

3.3 Increasing importance of research-based competence

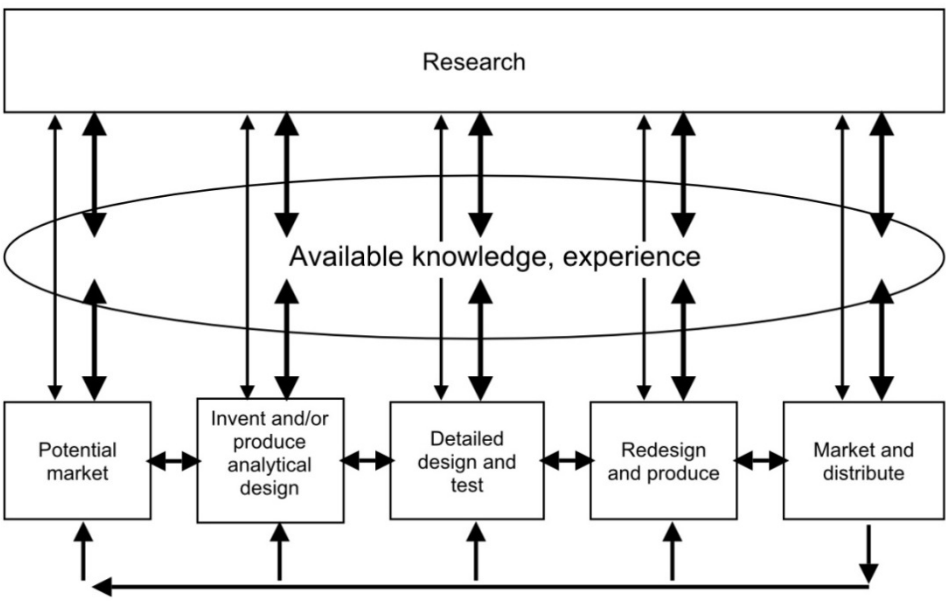
As discussed above, innovation is not a sudden flash of genius as such, but a long process of searching, before and after a new product or process sees the light of day. Research-based competences can contribute to the process in many different ways, but ideas for new services or products are not the only (or the most important) contribution from research.

[26] Hauknes (1999).
[27] "Need" is not a good term for this. The world is full of "needs" which are not met because no-one is prepared to pay the cost of addressing them.

Research plays an important strategic role in identifying future threats and opportunities wherein companies need to upgrade their competences. They do this long before there is any "idea" to commercialise.

Kline and Rosenberg[28] describe the relationship between research and innovation as an interaction between two parallel processes, each with its own goals, its own evaluation criteria and its own social contexts. Both contribute to and draw inspiration from a shared bank of knowledge and experience (Figure 2).

Figure 2. Knowledge flows in the innovation process



Source: Kline and Rosenberg, 1986

"New" results are not the only thing of interest in this context. Old results may gain new prominence in a new context. Knowledge is useful, not only as a source of ideas, but to help identify and solve problems at every stage of the innovative process. Taking advantage of this knowledge requires an existing familiarity with the field. It also requires (to the extent that knowledge is not codified and documented) access to the right contacts. This applies not least of all to "meta-knowledge": What are the key issues at the moment? Which research groups or companies excel at certain types of problems? And other such questions.

[28] Kline and Rosenberg (1986).

Scientists seek to isolate the phenomena being studied so as to find general relationships and identify basic mechanisms. Basic research cannot be directly translated into practical applications; industry has to consider how a mechanism works outside the pure laboratory milieu and in the specific context to which it will be applied.

A large share of research conducted in industry, as well as in collaboration with public research, is also about providing a basis to improve existing products or services. This should not come as a surprise. In the early stages of the innovation process, the focus is often on what a new product or service should be able to accomplish and on determining the inevitable trade-offs between different product characteristics. These trade-offs are not scientific issues but once a reasonably stable configuration has evolved, science can help identify new or better ways of meeting the requirements. [29]

Once a company has an early product or service on the market for practical use, it is also easier to see sufficiently well-defined problems and opportunities for improvement so that a research agenda may be drafted. One consequence of this is that innovation leads to new research perhaps as often as research leads to innovation. As Nathan Rosenberg noted "Science owes more to the steam engine than the steam engine owes to science". [30]

Direct interaction and dialogue between industry and public research is an important prerequisite for the effective transfer of knowledge. Such a dialogue assumes, in turn, that sufficient internal expertise exists within companies to identify the right partners and formulate the right questions.

[29] Abernathy & Utterback (1978).
[30] Rosenberg (1982).

4 Cooperation with academic research

In trying to solve the problems encountered in the process of developing an innovation, companies primarily search the existing knowledge base. Earlier research is part of this knowledge but has often been codified in review articles, books, etc. Starting a new research programme is costly, uncertain and above all takes precious time. New research is often a last resort when existing knowledge is simply not enough. Innovating firms will rely on their existing in-house competences in the first instance. Where these are not enough they will turn to their network contacts with external knowledge sources. Where the required technology is completely new to a sector they may need external support such a government supported programme or a consultant. R as opposed to D is mainly carried out by small high-tech firms which are usually focused on specialised fields in which they are experts or very large firms which maintain portfolios of promising technologies which can change frequently.[31]

An extensive body of research demonstrates an interaction that is far more complex and reciprocal than handing over research results for "commercialisation". Academic research and its contribution to business development is much broader than originating new product ideas or new technology-based companies[32].

The main contribution of universities in this process is to educate scientifically trained people. Their training enables them to navigate existing research and/or have enough understanding to estimate what direction and partners new research will need in order to succeed. They will also be able to make good assumptions about where to seek solutions to problems arising in the development process.

In the earlier stages, academic researchers can also serve as discussion partners to a business in its search for knowledge. This uses the researchers' overall expertise and network of contacts, giving an overview of their field but not necessarily of their research results. A publishing record is an entry ticket to the academic network; this makes academics useful as a guide to the broader research base. It provides access to research networks and thus an overview of what is about to happen within a field of knowledge and so on.

[31] Barber (2014).
[32] See e.g. Jacobsson & Perez (2011), Martin & Tang (2007), Salter et al (2000), Broström (2009), Hughes (2010).

4.1 Industrial motives for cooperation

A Swedish study of companies experienced in working with academic research shows various different reasons why companies choose to collaborate with universities:[33]

- R&D results in support of product and process development.
- Access to academic networks.
- Competence building.
- Direct business opportunities.
- Access to funding opportunities through national R&D funding agencies, EU programmes etc.

Even in regard to the first point (the direct results of R&D collaboration), companies consider "soft" results to be equally as important as "directly usable results." Collaboration with academic research provides a broader perspective on the potential of a technology. It thus highlights new ways to solve current problems as well as new business opportunities. Research collaboration can help with understanding customer needs better and suggest appropriate directions to seek solutions to technical problems (Figure 3).

Access to academic networks allows the identification of competences for future collaboration or recruitment and offers a neutral arena to interact with competitors and customers.[34] By demonstrating interesting new research directions, academic research can affect companies' own research focus.[35]

Collaboration also opens direct business opportunities for companies which package and sell academic expertise (consultancies). This also applies to enterprises in which scientists are an important market (instrument manufacturers, computers) and companies for which scientists are key opinion leaders (medical technology).

Figure 3. Anticipated results of cooperation with public research

EXPECTED RESULTS	**Area of use**	
	New innovation opportunities	**Support for current business areas**
DIRECTLY APPLICABLE RESULTS	Commercialisation of academic research	Applied R&D, problem-solving
"SOFT" RESULTS	Learning New perspectives New business opportunities	Understanding customer needs Identifying directions for search

Source: Broström, Anders(ed.) 2007

33 Broström, ed (2007).
34 Lester (2005).
35 Etzkowicz (1998), Faulkner & Senker (1994).

These findings are consistent with views expressed by Swedish companies on the benefits of participating in EU framework programmes.[36] Moreover, a study by Technopolis of industrial research institutes points to a division of roles whereby companies are increasingly turning to industrial research institutes for immediately useful results – problem-solving etc. and to universities for "horizon scanning".[37]

Academic research (and researchers themselves) contribute in many different ways[38] and product ideas are not the most important contribution. An important role is to help identify new directions in which to search. In this role, academic scientists can help provide an overview of the whole knowledge field – not just their own research results – as they have an ability to interpret and evaluate what is happening in their field. This overview is not just about new results; it also involves seeing where interesting things are happening and identifying the key actors.

In this context it is important to note that also many university spinoff companies start in this role; selling expertise as consultants, problem-solvers and discussion partners, rather than developing and marketing their own product.[39]

Universities also contribute by providing access to specialised infrastructure (clean rooms etc.) and "soft" infrastructure, methods, software, and so on.

The nature and extent of the contribution from academic research also differs between fields of knowledge. An important distinction is the difference between technologies that Rikard Stankiewicz has called "discovery-driven" and "design-driven"[40]. In the case of discovery-driven fields such as pharmaceutics, innovation is a process of discovery, verification and refining of natural materials or systems with promising features. This is where academic research can play a direct role as a source of new ideas and methods. In design-driven fields such as the engineering industry, the emphasis is on constructing a function by combining known elements into new and complex systems. In these fields, a university's role is more one of delivering a highly skilled workforce and assisting with problem solving, rather than serving as a source of ideas.

The distinction between the two modes is not clear-cut. As innovation is complex, there is often room for elements of both processes. The development of new semiconductor materials is largely a discovery-driven process, while the functions encoded in an integrated circuit are the result of a design process. New materials can play an important role in the choice and design of components in a system design.

[36] Elg (2006).
[37] Arnold et al (2006).
[38] Jacobsson & Perez Vico (2010).
[39] Bullock (1983).
[40] Stankiewicz (2000).

Jacobson and Perez Vico emphasise the diversity of pathways for utilising researcher expertise. Through education, universities can provide "avantgardists" who broaden a company's search for opportunities in new areas. When prominent scientists start a spinoff company to exploit a new technology, this can legitimise the technology and lower the threshold for other companies to dare to try it. Not only do cleanrooms and other specialised research infrastructure provide new opportunities to conduct research, they are also places where new informal networks develop. These networks may subsequently form the basis of new innovation.

4.2 Impacts on academic research

Policymakers often cherish the hope that innovation will follow directly as a result of public investment in research. Such interaction is described in terms of scientists "informing" a grateful industry of their latest results. As has been shown, R&D collaboration is not a one-way transfer of knowledge from universities to companies. Indeed, a number of impact studies at VINNOVA have shown the value of mutual learning[41]. It means that universities can get access to interesting problems; often more complex than could be recreated at laboratory level. This in turn means they pick up signals regarding issues which are emerging as important and their collaboration then opens the possibility of defining new areas of research.

Silicon Valley did not become the centre of the world's semiconductor industry because Stanford was a leading centre for semiconductor research. Around 1950, the transistor was invented by William Shockley's research team at Bell Labs, an industrial laboratory in New Jersey. In 1956 Shockley chose to leave Bell and found Shockley Semiconductor Laboratory in Palo Alto, south of San Francisco – the other side of the US. This area afforded him well-educated students, a pleasant climate and space to expand in the Stanford Research Park. There were also potential customers in the form of a cluster of electronics companies, with the US Air Force's missile programmes as an important end user. Soon, a group of employees followed Shockley's example, leaving his laboratory to start their own company, Fairchild Semiconductor. This later became the springboard for another generation of start-up semiconductor companies. The growth of these companies created a demand for students from Stanford University whilst collaboration with industry helped Stanford build up its competence in the semiconductor field.

[41] See Elg & Håkansson (2012) for a summary of these studies.

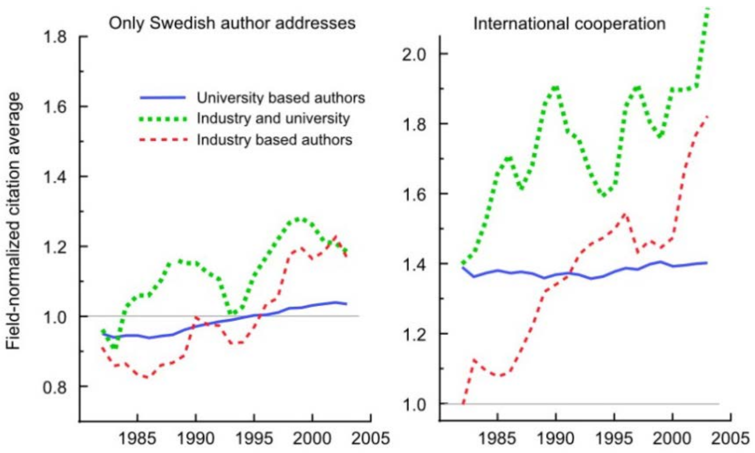
Cooperation with industry can improve academic quality

A recurring concept in the science policy debate is that academic quality is somehow opposed to cooperation with external stakeholders; that we must choose between academic "quality" and practical "relevance".

Contrary to the above, an early study at Chalmers University of Technology showed that those professors who ranked highest in scientific citations were the same ones who had the highest number of patent applications.[42]

A study by the Swedish Research Council also shows that articles produced in collaboration with industry were cited more often than those produced solely by academic researchers (Figure 4)[43].

Figure 4. Citation rates for articles with authors from industry, universities or in industry/university collaboration



Source: Karlsson & Wadskog, 2007)

An Italian study also showed that close cooperation between universities and companies contributed to scientific quality.[44] Direct interaction in cross-border networks of academic and industrial researchers contributed to increased productivity in terms of both scientific discoveries and new industrial solutions.

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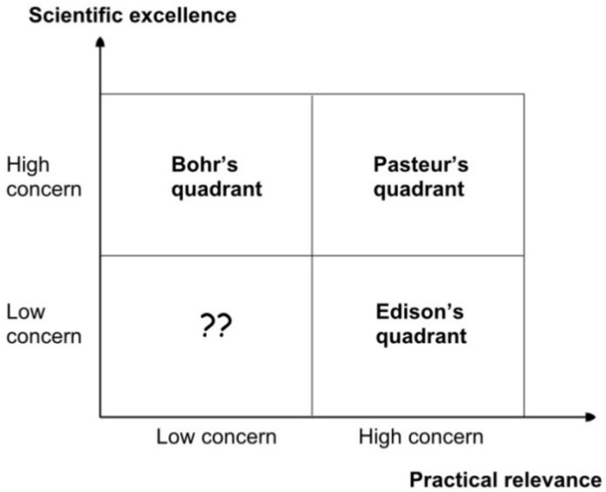
[42] McQueen & Wallmark (1984).
[43] Karlsson & Wadskog, (2007).
[44] Balconi & Laboranti (2006).

Science historian Donald Stokes argues that research findings must be evaluated according to two different dimensions: Scientific excellence, as judged by other researchers, and practical relevance, with the results helping solve practical issues.[45]

Stokes' analysis is useful in understanding several aspects of the European research policy debate. He summarises his reasoning in a simple figure:

Figure 5. Dimensions of scientific quality



Source: Stokes (1997)

In Bohr's quadrant, we find what we like to call "free basic research" where the focus is all on scientific excellence. In the opposite corner, Edison's quadrant, the emphasis is fully on practical use with little concern for whether the research is deemed to be at the scientific forefront.

The interesting aspect of Stokes' model is that it draws attention to a third quadrant: Pasteur's. Louis Pasteur laid the foundations of microbiology as a research field but this work was inspired by practical problems which he helped to solve. Stokes was tactful enough not to label the lower left corner, where the research neither advances research frontiers nor addresses significant practical problems. The fact that a majority of scientific papers are never cited by anyone other than the author (or his students) suggest that this box is not entirely empty.[46]

[45] Stokes (1997).
[46] This quadrant is sometimes associated with taxonomy, e.g. Audubon´s work on American birds. (Barber, 2014).

Another way of thinking about the relationship between excellence and relevance is to recognise that the concept of quality has two components:

Scientific quality means, first, that state-of-the art methodology has been used to address the question that was set. However, quality also implies that this methodology has been applied to a question which is "interesting"; the answer adds valuable new knowledge.

The first requirement applies to Bohr, Pasteur and Edison, all of whom created valuable new knowledge. The difference lies in whether the expected results are intended primarily to be of interest to fellow scientists (Bohr), practitioners (Edison) or both (Pasteur). Note that this criterion refers to the purpose of a research effort, a fact often defined by who pays the bill. However, exploring the unknown does sometimes yield surprises. Scientists who believe themselves to be operating in Bohr's spirit suddenly find themselves in demand by practical men and Edison's laboratory can find paradoxes that overturn established theories.

Obviously, the probability of this happening is greater if the doors between Stokes' different quadrants are not closed.

5 The need for innovation policy

In the economics literature, government support for R&D is usually motivated by a particular form of "market failure". The economic benefits of an R&D investment are assumed to be greater than the benefit to the individual companies or investors. As these cannot retain the full value of the knowledge generated, they do not always get paid for knowledge spillovers to other companies. Thus, economists assume that the sum of the investments made by private actors will be lower than the socially optimal level. This is seen as a possible reason for the state to increase the volume of R&D investment through policy measures.[47]

Nobel prize-winner Kenneth Arrow's arguments about market failure have been used to justify government support to public research. Economists also discuss whether the state might in some cases have reason to support R&D in individual companies. The theory of market failure has been used to argue for such support under certain conditions. However this theory provides little guidance as to how or in what extent governments should act, since the socially optimal level is not only unknown but is, in principle, incalculable.[48]There is an even more fundamental flaw in discussing "market failures" as an unfortunate exception to an ideal "perfect market". Any investment decision becomes impossibly difficult in perfectly competitive markets, as current market prices contain no information about the investment plans of rivals[49].

5.1 An evolutionary foundation for innovation policy

There are two main problems with the traditional way of looking at the role of government in innovation policy. As seen in previous chapters, innovation is not something which takes place and then diffuses through the economy, nor is it something which take place within a single firm. Innovations emerge in a complex interaction between different actors.

The second problem is that not only are companies unable to calculate the value of the knowledge diffused to others. Companies cannot, even in principle, calculate their own benefits from an innovation project. The long-term value will depend on how others

[47] Arrow (1962a).
[48] Barber (2009a).
[49] Richardson (1961).

choose to act in a long process where different actors try to assess their position and manoeuvre to improve it.

In his 1993 Nobel Lecture, economics laureate Douglass North noted:

> *"Neo-classical theory is simply an inappropriate tool to analyse and prescribe policies that will induce development. It is concerned with the operation of markets, not with how markets develop. How can one prescribe policies when one doesn't understand how economies develop?"* [50]

For these reasons, most OECD countries today develop their innovation policies in a framework founded on evolutionary and institutional research. This research aims to study how economies change, not search for elusive equilibria. By studying change processes in more detail, it becomes easier to understand what is happening; the disadvantage for policy advisers is that they also become more aware that the future is genuinely difficult to predict.[51]

The strength of the evolutionary research tradition lies in interpreting what happened, but it is not easy to derive simple and unambiguous policy recommendations since reality is complex. What can/should be done is almost always due to the specific circumstances of the individual case, there is no "standard prescription".

Evolutionary economists emphasise that those who make economic decisions are limitedly rational and influenced by previous experience. Companies and other actors may act competently based on the available knowledge, but that knowledge is limited. It costs time and money to expand the knowledge base and explore options for action. The competences one has today also affect the opportunities for taking advantage of new knowledge. This means companies will differ in their ability to make wise decisions about the future. There is no such thing as "the representative firm". Different actors have different access to knowledge, different capacities for evaluating it and varying ability to act on it.

The economic system is in constant change; innovations cannot be regarded as temporary deviations from a stable equilibrium. In this state of constant change, companies that are less successful in developing their capability through innovation will contract or fail, while successful companies grow. The interaction between this variety of business experiments and the market's selection of more successful ventures is seen as the main driver of economic renewal.

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[50] North (1993).
[51] See e.g. Barber (2003), Edquist & Malerba (2004), Lipsey & Carlaw (1998), Lundvall (2007).

Taking the lessons learned from evolutionary economics, one can also see that a company's decision-making problems are far more fundamental than just choosing between options where the benefits of each alternative can be calculated in advance:

- An R&D investment is associated with genuine uncertainty[52]. An investor does not know if a project will achieve its intended result, does not know what will happen in the outside world which might change the conditions and cannot predict how potential customers will value and use the project's results. The uncertainty in these respects is genuine. It is not possible, even in principle, to calculate the probability of success and so forth.
- Capturing and absorbing new knowledge is not free. It takes time and costs money to keep up with what is happening in the outside world.
- As discussed above, companies' abilities to absorb and evaluate new knowledge differ depending on previous experience. One consequence of this is that a company will primarily search for new knowledge in the vicinity of its current competence base.

5.2 Focus on system failures

The main concern of innovation policy today is not public subsidies to specific R&D projects conducted in individual companies. John Barber, a former chairman of the OECD's Committee for Research and Technology Policy (CSTP), points out that policy does not solely (or even primarily) influence innovation through marginal support for activities which are chiefly a corporate responsibility.[53] Public research, education, taxation, public procurement, infrastructure and rules of business are all areas where the state is a major player.

Nathan Rosenberg, economic historian and a portal figure of innovation research, indicates three main tasks for an innovation-oriented R&D policy:[54]

To promote the two-way exchange of knowledge between research and practice. Both need to learn from each other.

To create institutional arrangements for interdisciplinary, problem-based research, industry-university collaboration etc.

Shaping stable framework conditions that provide space and incentives for "entrepreneurial experiments".

[52] In a Financial Times column (Kay 2010), British economist John Kay argues that the rational decision modes modelled by economists can only be applied to problems that are "well defined", which is seldom the case in real life. Real problems are ill-defined, not only because we lack data, but because we do not understand the structure of the problem. The problem is not only that we do not know what will happen, but that we do not understand the range of possible outcomes. Such problems, Kay argues, can only be addressed through an experimental search process in which the goals are also subject to revision along the way.
[53] Barber (2009a).
[54] Rosenberg (1992).

From this perspective, innovative capacity depends on how well the whole innovation system works together, not on an individual component being "world-class".

Innovation occurs in interaction between actors who each have their own agendas, goals, reward systems, etc. Each actor also has a limited view of the whole. They usually don't see themselves as part of an innovation system, but know that success depends on the interaction with external actors; they are also aware that these, in turn, are connected to other relationships.

For effective interaction to take place, different actors need to coordinate their actions despite the above limitations.[55] This requires there to be: other competent actors within reach; links to these actors (or the possibility of developing such links); rules that allow coordination; incentives which mean all parties have something to gain by coordinating themselves. Such collaboration must be built from the ground upwards. It cannot be directed, but there is no certainty it will come about spontaneously; at least not right here, right now. This is a paradox which policymakers need to address. Policy can create better or worse conditions for interaction. Policymakers can foster the creation of new networks, but they will only survive if participants find it is worth their while to participate.[56] The task of a policy promoting interaction is to facilitate stakeholders in coordinating their agendas for the future. It is not there in order to "transfer research results" after the fact.

We must also keep in mind that innovation systems need to evolve. The members of a system and the connections between them will change over time as various competence needs come into focus. Likewise, systems will dissolve when they have served their purpose. Policy needs to take this into account so we do not preserve structures that were designed for yesterday's problems.[57]

5.3 Broadening industry's competence base

Goods and services are becoming increasingly complex. Not necessarily for the user, but under the hood and in the systems needed to develop, produce and deliver the product or service to the user. This complexity is also reflected in the breadth of competences to which companies need access, while more rapid change shortens the lifespan of necessary competences.

Companies do not have time or resources to build up internal competence in all fields and investments in knowledge run the risk of quickly becoming obsolete. Business R&D

[55] Metcalfe (2005).
[56] Barber (2014).
[57] Walker (2000).

activities are increasingly dependent on cooperation with external experts; with other businesses and with publicly funded research.

A sceptical finance minister is likely to ask whether the market will not resolve this on its own. If there is a clear benefit then cooperation will probably be achieved someday, but not necessarily today nor in his country.

The majority of today's public R&D support for businesses is not given as additional funding for an internal project within a single company, but as programmes intended to engage companies in joint R&D programmes with academic research and other businesses. Such support may be viewed, at least in part, as compensation for companies' willingness to share their expertise. It may also be viewed a way of motivating them to broaden their own search for knowledge and competences, rather than as a subsidy of the marginal cost of internal projects. Studies of companies' motives for participation in joint R&D also highlight motives such as exploring new areas of knowledge, identifying potential partners and so on.

Experience shows that companies primarily search for new solutions in the proximity of their current competence base. This affects both the information which the company takes in and how it evaluates this. Since the competence base is built into the company's organisation and contact patterns, it is difficult to broaden the search process, even when the company is aware that its competence base is threatened.

Kodak was among the first companies to manufacture digital cameras. Despite this, the company was unable to establish a competitive position in this market; neither could it utilise its photochemistry expertise in the paper copies market.

Ericsson was successful in transforming and developing its expertise in phone systems to become a world-leading supplier of digital mobile systems. However, Ericsson was forced to give up its business in mobile handsets, a fast moving consumer market far from the company's experience base.

As we have seen above, an important motive for industry to collaborate with academia is broadening the search for new knowledge. Studies of the impacts of needs-driven R&D in Sweden also indicate a number of obstacles to such cooperation. It is hard to make an advance assessment of the value to companies of engaging in long-term R&D collaborations. Not only is the outcome genuinely uncertain but equally often, companies find it difficult to forecast what long-term competences they will need. The academic peer review system also has difficulty evaluating and rewarding needs-driven R&D as this usually spans established disciplinary boundaries.

5.4 Defining new research agendas

An active dialogue between companies and academic research can help identify and define new agendas of research for needs-driven knowledge. This is demonstrated by a number of impact studies of R&D programmes supported by VINNOVA and its predecessors.

Sweden was late turning its attention to the new opportunities offered by the growth of microelectronics. The former Swedish Board for Technical Development (STU) played an important role in building electronics competence at universities when the universities themselves were slow in responding to the new technological possibilities. STU's contribution was mainly in providing a basis for expanding education in the field, rather than in any specific research results.[58]

A close interaction between visionary engineers, especially at Ericsson Radio Systems (formerly Svenska Radio Aktiebolaget), a group of academic researchers and STU was key to building competence in radio communications. This laid the foundation for digital mobile communications[59]. This research was initiated at a time when the area was considered stagnant within the mainstream of academic research. Furthermore, radio communication was not a priority among the top management at Ericsson; the focus at that time was on becoming a competitor in the personal computer industry. Consequently, the development of knowledge in radio communications may have been stifled by academic "peer review" or early demands for a formal commitment from Ericsson.

STU also accounted for more than half the academic biotechnology research funding in Sweden in the first half of the 1980s and was a key actor in getting Swedish biotechnology research off to a good start. The peer review-based Research Councils did not get involved in this field until after the public debate about the ethics of biotechnology had subsided, in around 1995.[60]

These were areas which for various reasons were not given priority in the academic peer review system. However, there was also no articulated industrial demand when research efforts were initiated. Neither did they spring from any superior strategic foresight at the public funding agency. Rather, the programmes were brought about by a financier who was willing to listen to visionaries in both business and academia, who was prepared to invest in new research fields and who had the political capital to get away with it.

[58] Jacobsson (1997).
[59] Arnold et al (2008) See also section 2.4. Being located at a distance from Ericsson headquarters also enabled Svenska Radio to maintain its own corporate culture, with a stronger emphasis on collaborating with academic research.
[60] Granat et al, (2002).

The purpose of such a dialogue is not to prioritise between different areas already on the agenda. The aim is to develop jointly new agendas for research and development, in a process that Gibbons et al described as “Mode 2” research[61]. According to the authors, Mode 2 research is typically based on a problem context and carried out in networks which include multiple academic disciplines as well as problem owners.

In the Swedish debate, Mode 2 has sometimes been dismissed (especially by those who dislike the concept) as just another label for “applied research”. However, one of its key points is that the concept describes a process in which new knowledge is created in dialogue with use and can only be created in such a context. It does not entail knowledge previously produced in academia being subsequently adapted to an application. At the same time, other authors have criticised the idea that Mode 2 is something new. They argue that, on the contrary, this has historically been the normal form of academic knowledge production and that the post-WW2 focus on scientific autonomy is the exception that needs to be justified[62].

An important prerequisite for these efforts was that, at the time, a single funding agency could act across the whole range between basic research and technology development. Today, public funding is divided among a larger number of actors, each with narrower responsibilities. To initiate similar processes in the current situation requires several actors to be willing to coordinate their actions. It is not enough to enter a requirement for “collaboration” in an agency’s appropriations in order to achieve this; the various actors need to develop common visions of the future which permeate throughout the organisations. How this can be achieved will be revisited in chapter 6, “Lessons for an innovation-oriented R&D policy.”

Any policy which tries to define research agendas risks being accused of “picking winners”. Public agencies cannot predict whether any particular technology will succeed, but they should be better placed than an individual agent to consult a broad range of opinion in order to develop a portfolio of program, some of which might succeed.[63]

5.5 Making room for business experiments

In addition to R&D programmes aimed at boosting their industrial competence base, most countries have some form of public support for young, innovative companies.

New businesses play an important role in long-term industry dynamics. They serve as experimental workshops for new business ideas that do not fit into existing corporate portfolios and for testing different ways of exploiting new technological opportunities.

[61] Gibbons, Michael et al (1994).
[62] Etzkowiz & Leydesdorff (2000).
[63] Barber (2014).

As has been demonstrated by information and communications technology and biotechnology, this role is particularly important when a new generic technology opens up a broad range of possibilities.

The role of such companies' as experiments with something new and untried makes it difficult for private investors to assess their risks and development potential. In most countries therefore, the government has taken on a special role in financing the early stages of their development. An example is the U.S. Small Business Innovation Research (SBIR) programme, a programme in which federal agencies allocate research contracts to small, knowledge-based service companies. A study shows that SBIR serves as an incubator in which companies qualify for possible downstream funding from private venture capitalists. About 10 times more companies participate in the SBIR programme than those receiving private equity investments.[64] In Sweden, 22 of the 33 companies identified as "Sweden's hottest technology companies 2014" by a major business publication had received some form of support from VINNOVA.

An impact study of several programmes in Sweden relating to the early financing of technology-based companies (known as seed funding) shows this support had created significant additionality.[65] New business platforms had been built and tested, the companies had grown twice as fast as a control group and several companies had reached a significant size. Not only had the support improved the companies' ability to attract continued funding from the private sector, according to the interviews with supported companies, it had been a deciding factor.

5.6 Keeping options alive?

The market can only select which technologies will have the opportunity to develop further from the options available at a given time. As technologies are not born fully developed (and as we cannot predict their potential) it is not certain whether the market chooses what would be the optimal alternative in the long run. A classic example is the keyboard on our computers: Early typewriters had problems with typebars getting tangled up together. The QWERTY keyboard was developed to avoid these tangles and made popular by the success of Remington's No 2 typewriter, introduced in 1878. By the time technology had solved the problem of tangling, most typists had learned typing on the QWERTY layout and over 100 years later, no arguably more efficient design has been able to replace it.[66]

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[64] Block (2009).
[65] Deiaco et al (2008).
[66] David (1997).

Earlier, it was noted that a new technology or radical innovation is often born in embryonic form. It can rarely compete directly with established alternatives, as long as competition takes place on the terms of those established alternatives. To survive and develop, innovations must often first gain a foothold in niches where they can offer particular advantages.

The first digital cameras were expensive and offered poor image quality. Photographic trade journals agreed that digital offered no threat to "real" photography (this was only 20 years ago.) However, digital cameras had one unique advantage. A news photographer could take a picture and within a few minutes transfer the image over the phone to the editors. At that time, image quality was less important to newsprint.

This raises the question of whether there is a role for innovation policy in helping more options to be further developed, in order to allow the best long-term options to have a better chance of being tested in the market.[67] This question becomes especially relevant when society has an interest in moving ahead with solutions to pressing problems, such as environmental issues.[68]

Economists are inclined to recommend "technology neutral" performance standards, but Bergek and Jacobsson (2010) argue that this type of policy will only reward incremental improvements to existing technology while more radical solutions are disadvantaged. In addition, in the energy market products like electricity and district heating are "homogeneous" (all electricity looks the same to the end user). Initially this makes it difficult to find niches in which to develop more environmentally friendly production methods until they are competitive on a broader market.

Meanwhile, the question remains as to how long policy can or should keep its options open? If we are too impatient, we run the risk of not reaching a possible breakthrough; but with limited resources there has to be a prioritisation at some stage.

Technology historian Joel Mokyr describes new technologies rather radically as "hopeful monstrosities"[69]. Monstrosities because in their early incarnation they are often expensive and impractical, but hopeful because they extend the hope of future possibilities. After more than 60 years, it is still expected that fusion power research is decades from finding any practical application; still, its potential benefits make the world go on investing billions in fusion research.

[67] In the early 1980´s the UK government gave £2 million to support the development of the BBC Micro. This helped Acorn Computers to establish a UK capability in RISC chips. Acorn developed into ARM Holdings, today a major international chip design business (Barber, 2014).
[68] Geels et al (2008).
[69] Mokyr (1990).

5.7 Innovation addressing social challenges

Innovation policy has been viewed primarily as a means to strengthen the development capability/long-term competitiveness of countries or regions. Over the past few years, increased interest has also developed in using innovation to address other major social challenges. When OECD was commissioned to develop an innovation strategy in 2007, work focused on how increased innovation can meet “grand” societal challenges such as climate, health, access to food and combatting poverty whilst contributing to sustainable growth. The project was initiated by OECD’s highest governing body, consisting of the member states’ finance ministers.

Innovation as a means of achieving other policy goals is not in itself new. Technology procurement for defence or healthcare are both examples of this. What is new in today’s discourse is partly the magnitude and global nature of the challenges, but also the realisation that innovation’s experimental search processes can sometimes lock us into dead ends that subsequently prove unsustainable.

As an example, breaking our dependence on fossil fuels requires not only that newly developed powertrain technologies must compete with 150 years of experience with internal combustion engines, which can be difficult enough as discussed in the previous section. It also requires large areas of automotive innovation systems to be replaced or rebuilt and entails a need for a variety of complementary innovations plus a whole new infrastructure for distributing alternative energy carriers and for maintenance and repairs etc.

The political challenge is that we need to develop new innovation systems, not just innovations. We also need to do it quickly if we are to avoid the catastrophic evolution of global warming. Meanwhile, previous experience underlines how new innovation systems cannot be designed from the top down but must be allowed to emerge organically. What policy can still do to promote such a development is the subject of a new OECD project on “Systems Innovation” which started in 2012.

5.8 Globalisation changed the policy playing field

An increased share of global companies free to choose the most advantageous places to invest in R&D has made research funding and R&D support a competitive factor between countries and regions, as they seek to maintain their attractiveness as alternative locations for companies and their R&D. An early example of this was in the 1990s, when General Motors was able to play off Rüsselsheim against Trollhättan when deciding where production of the next Saab/Opel model would be located.

Sweden’s innovation capacity is uniquely dependent on a small number of large and successful companies. Innovation policy needs to focus on both the conditions for the creation and growth of new knowledge-based businesses and on motivating existing companies to choose Sweden as a base for skilled parts of their value chain. In the past twenty years, these companies have largely come to be part of larger international groups. Today about 30% of business R&D in Sweden is conducted by companies headquartered outside Sweden.[70] Other European countries are in a similar position. Large firms tend to carry out research close to centres of excellence, while development work tends to be located close to major markets.

Enterprises which are still Swedish-owned also have a significant portion of their operations outside Sweden and foreign market demands are more important today than the domestic market. Meanwhile other countries, particularly in Asia, have caught up or surpassed Europe in terms of investment in education and research. Globalised companies can choose freely where they want to locate their R&D and other high value-added activities. This applies to companies' own operations as well as their selection of external partners. Globalised companies have a different relationship to the national innovation system than companies that were clearly "Swedish" 30 years ago; they can choose to relocate R&D to countries with better conditions.

When companies nevertheless choose to pursue a major part of R&D in Sweden it is largely for historical reasons. R&D activities were once developed in Sweden and the importance of tacit, non-codified expertise makes relocation less than straightforward.

This temporary advantage can be eradicated when a shift of technology base turns the old tacit knowledge into a liability rather than an asset.[71] In this case, an international company can seek cooperation with the strongest knowledge milieus wherever they are, rather than having to settle for the best available partners at home. The threshold for this has been lowered, on the one hand by an increased use of information and communication technologies, and on the other by companies gaining experience in networking and operating internationally.

The role of policy in a globalised system perspective

In a globalised world, an important role for policy is thus to make it attractive for companies to locate high value-added activities in a country or region and to anchor existing companies in the local innovation system. One important way of doing this is to create competent milieus for research and innovation in areas of interest to business. Another is to create stronger links between these milieus and businesses.

For a small country like Sweden, such a systems-based innovation policy can no longer attempt to optimise a more or less complete national system of innovation. Rather, the

[70] Tillväxtanalys (2011).
[71] See e.g. Henderson & Clark (1990).

task for policy is to decide what roles we will aspire to in various globalised innovation systems. This also requires specialisation. We must become the best in the world at something instead of being "good enough" at everything. Saab Aerospace can no longer build an entire aircraft (like the SF 340) and so today tries to position itself to take roles in international aircraft consortia and to become the best in the world at a few subsystems.

6 Lessons for an innovation-oriented R&D policy

As noted in earlier chapters, innovation capacity is affected by decisions made in a range of policy areas that all need to pull in the same direction. It may involve the: regulations and incentives affecting those who want to start or expand businesses; availability of skilled personnel; demand for innovative solutions and so on. This paper has focused on the role of policy related to building competences for future innovations.

6.1 Focus on learning

An innovation process has two kinds of results. In the best case, the process gives rise to (1) a new product or service that is successful in the market, but whether it succeeds or not, those involved will (2) have learned things along the way; knowledge affecting what can be learned in the future and how new knowledge will be evaluated. (Of particular value is knowledge of what did not work, especially if there is an understanding of why it did not do so this time.)

Learning is also a prerequisite for innovation. Ideas do not come as a flash of genius from a clear blue sky. New combinations of existing knowledge require a large toolbox of knowledge elements which can be combined.[72]

Furthermore, as noted earlier innovations are not born fully formed. Interacting with early users is an important part of the innovation process. This process involves learning to better understand the needs of different users and see how an innovation works out in reality.

As Bengt-Åke Lundvall notes, R&D is just one of several sources of knowledge for innovation. Lundvall discusses two modes of learning which interact with each other in the innovation process: ST (Science & Technology), research & development within or outside the company, and DUI (Doing, Using, Interacting), learning in production, learning from users/customers and learning through interaction with a broader base of knowledge sources.[73] In addition to Lundvall´s discussion, learning in production was described by Kenneth Arrow[74]; and learning from users as previously mentioned by

[72] Arthur (2009).
[73] Lundvall (1988).
[74] Arrow (1962b).

Rosenberg[75]. All three authors build on a broad empirical literature describing phenomena. The works in question have mainly tried to link empirical data to economic theory.

Another way to describe this is that policies should aim to strengthen the capacity of actors to take advantage of new knowledge ("absorptive capacity")[76] and turn knowledge into new processes, products or companies ("dynamic capability")[77].

Direct interaction/dialogue crucial to learning

Continuous interaction between academic researchers and industry is a prerequisite if learning is to take place, because academic research has the potential to contribute in many different ways and at different stages of the innovation process. Several of the studies referenced earlier suggest that the role of researchers as a discussion partner and sounding board is valued by industry. Yet to fulfil this role, academics also need to be aware of how industry sees its long-term knowledge needs.

Creating venues for interaction between industry and academic research (and processes to create shared visions of the future) has become an important task of innovation policy. Contributing in this way requires research policy to put a premium on openness to contacts and interaction with the surrounding community. So it can seem in political rhetoric, but academic incentive systems do not always pull in the same direction. For a continuous interaction to be meaningful and perceived as valuable by both parties, those parties need to get to know each other and build trust. R&D programmes in active collaboration create venues where this can happen.

6.2 Policymaking must also be a learning process

Policy needs to identify and seek to strengthen the weak links in national parts of the various innovation systems. This requires policy actors who are sufficient familiar with the specifics of different systems, plus an understanding that policy must be flexible and allowed to adapt to different conditions.

Policymaking needs to be based on learning. An important lesson of this paper is that the scope for meaningful political actions (and how these should be designed) cannot be determined once and for all based on theoretical considerations. The only way forward is to test various options and be honest in assessing the results. Moreover, be prepared to reconsider measures that worked poorly and be prepared to learn from mistakes instead of trying to bury them.

[75] Rosenberg (1982).
[76] Cohen o. Levinthal (1990).
[77] Teece et al (1997).

When there is no simple recipe for the optimal design, the ability to learn becomes an important element of policy development. This applies when it comes to drawing sensible lessons from the experiences of others (where we take into account differences in conditions) and when it comes to learning from your own experiences and allowing these to affect future policies. It is important to avoid uncritical imitation of policy initiatives from other countries without allowing for differences in policy context.

6.3 The need for policy coordination

Even if we restrict our field of view to that part of innovation policy concerned with the innovation competence base, there are still many actors who must pull together for policy to be effective. Support for needs-driven R&D is currently divided among a number of stakeholders; government agencies, foundations, EU programmes, and so on. From a learning-centred perspective, policy also needs to take into account the education system's ability to function, businesses' need for skilled employees and so on.

There are two reasons why getting this broad set of actors to pull together does not happen simply by including the word "collaboration" in various agencies' briefs: firstly, the roles of such agencies are too complex to be followed up with a single indicator of effectiveness, and secondly, successful cooperation requires the involvement of various independent actors, each with their own goals and strategic agendas. No single actor has command over all the others.

A better way to help coordinate the actions of various participants is to have mutual understanding of each other's world views. This allows the identification of collaborative opportunities by:

- increasing the area of shared knowledge;
- reducing misunderstandings about each other's world view and intentions;
- developing a better understanding of each other's world view and intentions, in the areas where they still differ.

In some cases, a process in which each actor makes their own decision in the light of a common world view may lead to sharper local decisions than if a joint decision were to be forced upon them – which would necessarily be a compromise. This can create a stimulating competition between actors.

To be constructive, such competition requires a moderate overlap between actor's arenas, so there is an area to compete in - but not too much overlap. Each actor needs to possess unique capabilities which are needed and valued by other actors.

Collaborative learning is also an important way to coordinate different policies towards common goals. The need for learning in innovation policy was the main theme of an

OECD project on the coordination of innovation policy (MONIT)[78] as well as an important element in the Swedish government's recent innovation strategy.[79]

A number of different strategy tools have been developed to build common views of the current situation, future threats and opportunities: Roadmaps, Foresight, SWOT analyses and the like. Such tools have two functions in that 1) they generate findings and recommendations that others can take advantage of and 2) experience has shown an equally important function is as a joint learning process for those involved in the process. By involving key stakeholders their collective learning contributes directly to the strategy process.

6.4 Looking forward

Policies designed to meet industry's long-term needs for research-based competence must balance the risk of being too responsive to industry's current needs at the expense of future competence requirements against the risk of being seduced by deserving social needs that are not linked to any real demand. (Demand does not materialise simply because we see a problem, there must also be someone willing and able to pay to get the problem solved.)

R&D policy has long lead times and needs to be proactive. R&D priorities today will affect what competences university graduates will bring to the labour pool some years later. Building up a new research field with critical mass takes at least 10 years. Such competence development cannot be based exclusively on public-private partnerships with current business, or upon their current preferences. Businesses are normally preoccupied by today's competence needs. Moreover, when new competence needs become evident, globalised companies can pick and choose where to locate R&D cooperations or new business activities.

Project or programme-based funding?

Support for individual R&D projects and longer-term programmes complement each other and fill different roles: Individual projects can identify and test the potential of new knowledge fields at an early stage. More comprehensive programmes are an important tool for building and disseminating expertise in areas that seem viable and where the business community has demonstrated a willingness to get involved.

The study of digital radio communications mentioned earlier[80] shows how a number of different mechanisms combined to build a knowledge base for Ericsson's development of

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[78] OECD (2006).
[79] Den nationella innovationsstrategin, Regeringskansliet N2012:27.
[80] Arnold et al (2008).

digital radio technology. Its origin was in an informal network of R&D managers at Ericsson Radio Systems and a couple of university research groups. The contribution of public policy evolved through a variety of efforts over a long period; more than 30 years. These included individual projects, programmes and initiatives to create national programmes (The National Microelectronics Programme). An important point of Arnold's analysis is that the early competence development evolved in dialogue with "odd" visionaries in both Ericsson Radio Systems and academia. Early demands for a formal commitment from Ericsson would have killed this process.

Flexibility in programme design

Each policy action differs with respect to the character of the knowledge area, actors, stakeholders and others involved. For this reason, it is important to combine a clear idea of the desired achievement using flexibility, in terms of programme design and programme management. Different knowledge and application areas have different development logic. Interaction with the research system will therefore differ in character.[81]

How companies capture new knowledge as well as how and with whom they interact in this differs between different areas/industries etc. One aspect discussed earlier is the difference between industries in which innovation is based on new product configurations (such as engineering) and industries in which the basis for innovation is to search for substances with new and improved features, such as new materials or drugs.[82] In an influential taxonomy, Keith Pavitt describes how some industries acquire new knowledge primarily from their suppliers, while direct contact with research plays a major role for others.[83] However, even companies in the same industry (and in the same country) may have chosen different strategies.

Policies must take into account these different conditions and not attempt to apply a standard policy design to all areas. A British meta-analysis of a number of programme evaluations emphasises that success of a programme or policy is determined by how well adapted it is to the target group's needs and innovation strategies.[84] In addition to the need to tailor programme design to the target group's characteristics, the study emphasises the importance of a programme addressing problems and needs that are seen as important and relevant by the target audience. Both of these factors require a good knowledge of, and continuous dialogue with, the actors one wishes to involve.

[81] Elg & Håkansson (2012).
[82] Stankiewicz (2000).
[83] Pavitt (1984).
[84] Barber (2009b).

Things seldom go as planned – staying flexible

It is important to be flexible, not only in the original design of a programme, but also throughout the process. Several of the above mentioned studies have shown that even in cases where a programme yielded valuable results, they were not always of the character initially anticipated.

For example, the Swedish National Microelectronics Programme (1981) was intended to develop national manufacturing capability in microelectronics components. As this capability was deemed strategically important, similar programmes were launched in several countries at around the same time. These aims severely underestimated the economies of scale in the production of such components, with the result that production of standard integrated circuits was concentrated in a few, very large facilities (or "fabs") for the global market. Instead, the programme built up research capacity in the field. This helped make Ericsson a more competent buyer of components and gave it expertise in digital signal processing; an important prerequisite for Ericsson's success in mobile communications.[85]

6.5 Can we measure the impacts of policy?

An important part of a learning innovation policy is systematically studying the impact of efforts made. Governments – and taxpayers – have a legitimate interest in knowing that the resources invested in innovation and research policy are providing a reasonable return to society. Even so, if we do not respect the fact that this relationship is complex, there is a risk of policy being guided by the overly simple indicators that happen to be available – we will be searching under a streetlight.

Long-term impact studies (done for VINNOVA by external researchers and consultants) show the impacts of public support for R&D on industry and society to be the result of processes over time. Various private and public actors will have interacted, with the impact of public support depending on how and when policy intervened, not just on "subsidy levels".[86]

Taking a historical approach, we can form reasonably credible views as to whether public support played an important role, how this happened and what factors were important in order for such impacts to occur. This provides valuable lessons to consider when designing and implementing future programmes. Lessons cannot be directly translated into simple recipes for success because the conditions will be different. However, they do provide a better understanding to help with interpreting new situations.

[85] Bergek et al (2008).
[86] For a meta-analysis of these studies, see Elg & Håkansson (2012).

Econometric studies of the impact of R&D support have mainly focused on quantitative effects:

- Does R&D support lead to more R&D, or is it a pure subsidy of investments that businesses would have done anyway (input additionality)?
- Does R&D support contribute to faster growth than that of a control (output additionality)?

Studies of this kind provide a limited view of policy impact, in several different ways. As noted earlier, innovations develop in a complex interplay between private and public actors. One important consequence of this view is that the innovation system's performance depends on how well its different components work together. There is no automatic link between R&D and growth – investment in R&D is not a homogeneous product. More important than how much you invest is whether there was investment in the right areas and how these investments were leveraged.

In an innovation-oriented R&D policy, the main ingredient is no longer subsidy to individual companies but the support of other actors in the innovation system in creating better milieus for companies' own innovative activities. This is particularly applicable in Sweden which, in international comparison, has one of the lowest levels of direct R&D subsidy to businesses.

According to OECD a more important role for policy is innovation policies affecting the qualitative content of corporate R&D (behavioural additionality). R&D support can facilitate participation in longer-term R&D, increase interaction with external sources of knowledge, or influence where businesses choose to locate their R&D activities.[87] Public support can induce firms to consider a wider range of technological options and/or opt for more radical technological solutions. This increases the chances of significant commercial success but increases the risk of technological and financial failure, with the latter being partly offset by the funding provided. Innovations which are more radical in nature tend to be accompanied by greater externalities and therefore by a larger excess of social over private returns.[88]

As discussed in Chapter 4, the contribution of academic research to industry is not primarily to generate new product ideas. Rather, it provides a competence base for the development of business and products. This means that impact studies focusing only on the financial results of individual projects will fail to capture those impacts that enterprise itself deems important. This is because a large part of the benefit is being better able to make wise decisions in future.

[87] (OECD (2005).
[88] Barber (2014).

By measuring the effects on enterprises which have received support, we also fail to capture the indirect impacts on customers, suppliers and competitors.

The main measure of usefulness is probably the fact that a number of businesses find it worthwhile to invest money and their staff's time in long-term cooperation.

Far more problematic is retrospectively attempting to quantify the size of effects, or how much different actors contributed to them and, on that basis, determine whether a specific action has been cost-effective. This is in part because of the long time periods involved and the difficulty allocating impacts between interventions by different actors. Whether a specific type of support has played a role depends on when and how the policy intervention was provided, not only (or even solely) on the volume of support.

Policymakers will still continue to expect answers on whether public support has been "profitable". In this context, the deeper understanding provided by impact studies can help specify econometric analyses based on a more realistic picture of the process being modelled. Innovation processes involve multiple actors over long periods of time. For this reason the closer in time we measure, the more likely it is we can allocate effects to a specific cause, but the fewer long-term effects we can capture.

Governments are not alone in grappling with this problem. Industry is no better able to calculate how much it should invest in R&D than which projects would provide the greatest return. It looks at how much competitors invest and how much it can afford. The selection of projects invested in is based on how a project complements other projects in the long-term strategy, not on the marginal return from individual projects.

6.6 What about the "research paradox"?

In the Swedish debate it is often claimed that the country is getting a poor return on the investments made in research in Sweden; the "Swedish paradox" concept. At the European level we saw the same idea of a "European research paradox" as the driving motive behind the Lisbon Declaration's target of 3% of GDP to R&D in the Union.

Originally the "Swedish paradox" discourse referred to a supposed lack of connection at the national level. Sweden seemed to get poor returns in terms of GDP growth from large overall R&D investments. Ejermo et al have examined this and concluded that a lack of return can only be seen in fast-growing industrial and services sectors[89]. Their interpretation is that this cannot be seen as a malfunctioning innovation system, but as a necessary cost of competing in these fast growing markets. A further explanation is

[89] Ejermo et al (2011).

that corporate R&D investments by large multinationals with roots in Sweden result in production in other countries, in a globalised business.

Although Sweden stands out primarily in terms of large corporate R&D investments, the debate soon came to be interpreted as poor returns on public investments in university research. Granberg & Jacobson note there is no empirical basis for asserting either that we get a poor return on public R&D investment, or for arguing the opposite case.[90] Attempts made to measure the return cover only a small part of the mechanisms by which universities interact with society. Similarly the available crude indicators, such as the number of companies started as spin-offs from academic research, do not support the claim that Sweden would do worse than other countries.[91]

This does not mean there is no room to improve Sweden's ability to benefit from investments in R&D, but the talk of a "paradox" is not a good starting point for analysing what improvements can be made, or need to be made.

[90] Granberg & Jacobsson (2006).
[91] Jacobsson, Dahlstrand & Elg (2013).

7 Conclusions

For innovation to happen we need two things. We need actors – entrepreneurs, innovators, lead users, researchers and financiers willing to take risks in order to create something new. We also need a learning milieu that gives them something to work with. This paper has focused on the latter aspect but does not imply that entrepreneurs or innovators are less important.

Research-based competence (and cooperation with academic research) can contribute in many different ways in the innovation process: by adding new competence, by identifying new areas of knowledge that may present threats or opportunities, or by identifying and solving concrete problems. "Product ideas" are not the most important contribution of academic research nor are they the main reason for companies to seek cooperation.

What the reader should take away from this report is that innovation is fundamentally about long-term learning, and the main challenge for an innovation-oriented R&D policy is creating a good milieu for such learning, within and between enterprises, research groups and other stakeholders. A long-term learning that requires sustained cooperation, in close contact with real applications.

Innovation cannot be created by government actions; they emerge organically and are constantly evolving. Still, with forward-looking measures innovation policies can improve the conditions for such processes by removing administrative obstacles and through programmes that increase awareness of the expertise available and demonstrate the benefits of cooperation.

Historical studies of how innovations have been created demonstrate that innovation does not occur as a sudden brainwave which is then simply "commercialised". In most cases, innovations have been preceded by a lengthy search process whereby different actors have searched for solutions, tried and failed. Neither are innovations born fully developed. Value is created when the original seed is nurtured and developed.

Innovation is a complex process, based on expertise from many sources which needs to be integrated. Research is one of these sources but often reaches the application stage embodied in manuals, consulting or subcontracted components/subsystems and advanced materials.

The necessary competences also have a limited lifespan. It is neither possible nor desirable for a company to internalise all competences. Innovations are therefore based on collaboration with others – customers, suppliers, consultants, researchers – in networks that we call "innovation systems".

Academic research is one of these sources of expertise, and its importance is increasing in many fields. However, in order to contribute it is not enough to "transfer research results" after the fact. Researchers can contribute more than their own recent results and at many stages of the innovation process. However, if this is to happen, it requires companies and researchers to understand each other's concerns and world views and to trust each other.

These are all learning processes: The parties involved learn over time where to find expertise, which solutions work, which ones don't (at least as important to know), or what characteristics customers really want.

Another way to describe this is as two parallel experimental search processes, seeking answers to the questions of, "what are we going to accomplish?" and, "how could we do it?"

Each innovation represents a compromise between different requirements that are often in conflict. What trade-off between various characteristics of a product or service which is the "best" cannot be predicted a priori. We do not know in advance what compromises we will need to do and users find it difficult to articulate what they really want before they have the opportunity to try.

Furthermore, there are usually several possible ways to deliver a desired function. Before such solutions are fully developed, it is difficult to assess the level of performance that is achievable in the longer term with each solution. Sometimes what is the "best" option depends on how competitors act; for example, which operating system will win the most users and therefore be able to offer the widest selection of applications.

Each innovation project yields results of two kinds. In the best case (and with luck) a new service or product on the market, to strengthen the innovator's competitiveness. Whether or not that goal is reached, the actors involved will have learned things which will affect how they evaluate future threats and opportunities and their ability to meet those threats and seize those opportunities. In the long run, the most important results are these lessons.

To answer the question of what policy can do to promote this, we can return to Nathan Rosenberg's three tasks for an innovation-oriented R&D policy: [92]

[92] Rosenberg (1992), see also section 5.2.

Research and practice both need to learn from each other. Policies must therefore promote a continuous, mutual exchange of knowledge and experience, not seek to retrospectively "transfer knowledge".

This requires policy to create institutional arrangements for interdisciplinary, problem-based research, in collaboration between academia and users. The most important factor is not organisational designs, but a reward system that values such interaction. Cooperation must be profitable for both parties, consistent with their goals and values.

Policy must also create stable framework conditions that provide space and incentives to "experiment" with new business ideas. This is also the main reason for supporting start-up companies. Not to subsidise individual companies but to broaden the range of experiments that the market selection process can then work on and to inspire others to dare to try.

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10 Innovativa kommuner - *Sammanfattning av lärdomar från åtta kommuner och relevant forskning*

11 Design av offentliga tjänster - *En förstudie av designbaserade ansatser. Only available as PDF*

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