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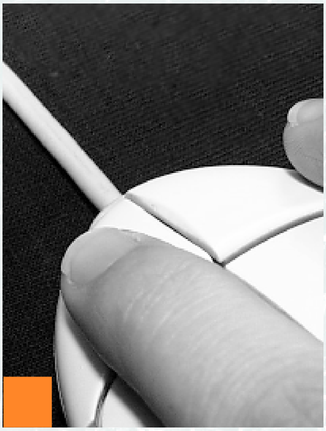
The Welfare Society in the 21st Century

Keith Smith



INNOVATION

Economic growth and "low-tech" industries

Fafo

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Issues for Norway

Keith Smith

Fafo

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Preface

This report is one of the products from a project entitled *The Welfare Society in the 21st Century*. Funded by the Norwegian Confederation of Trade Unions (LO) and the Norwegian Labour Party in commemoration of LO's 100th anniversary in 1999. The project spans a broad range of issues, including economics and working life, everyday life and civil society, social services, social security and welfare state distributions. A number of publications show how Norwegian society has developed in recent decades, and discuss challenges and opportunities on the threshold of a new millennium.

The project is based on contributions from scholars in Norway and abroad. Some reports are based on papers delivered at seminars while others are the result of more comprehensive studies. A list of all publications resulting from the project – a total of 44 reports and the main book *Between freedom and community* (in Norwegian only) is annexed.

The project has been directed by a project group headed by Ove Langeland and otherwise composed of Torkel Bjørnskau, Hilde Lorentzen, Axel West Pedersen, and Jardar E. Flaa and subsequently Reid J. Stene. The group received useful and constructive comments from several colleagues at Fafo and from other sources. Jon S. Lahlum has ensured that the reports are published in professional form. The project group would like to express its gratitude to the sponsors for making the project possible.

Oslo, April 1999
Ove Langeland

Abstract

The purpose of this paper is to clarify some relationships between innovation, industrial structure and economic growth. The basic argument of the paper is that what we might call "high-technology" models of growth misrepresent the nature of the growth process in advanced economies, especially in smaller economies.

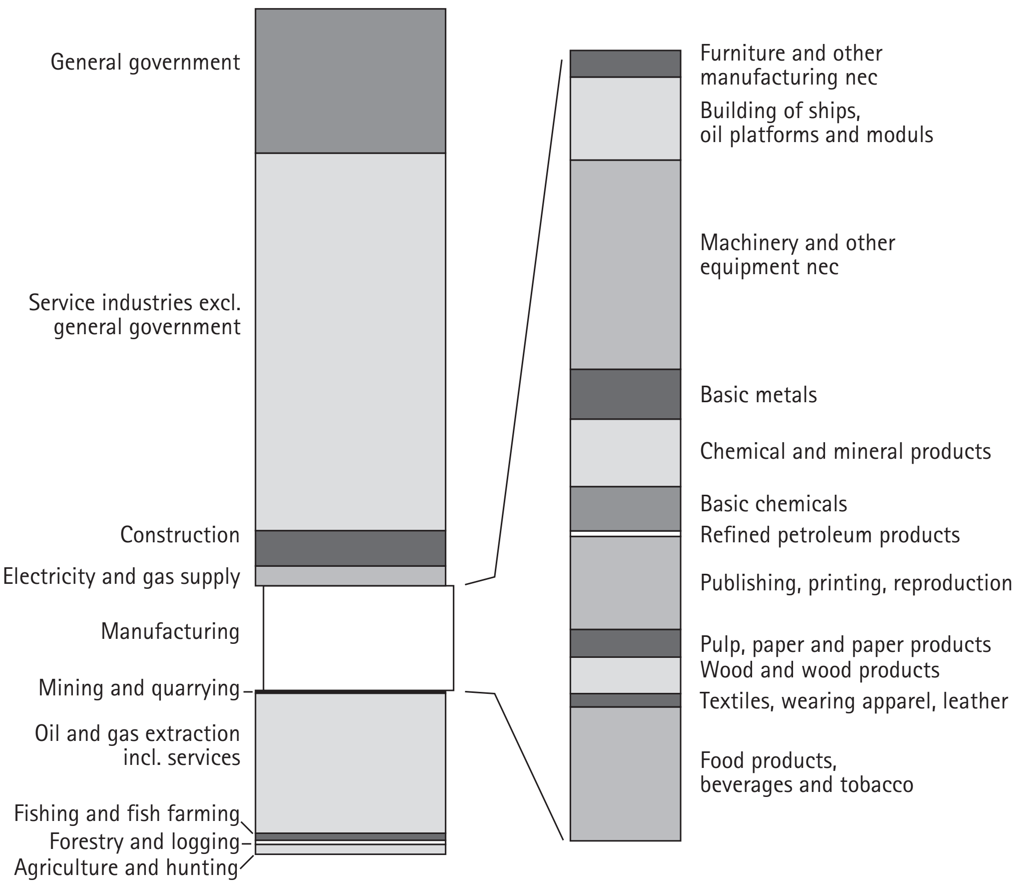
It is often argued, in the Kuznets-Schumpeter tradition, that economic growth depends on the creation of new industries, involving major new technologies, and that the latter are in some sense clustered together. At the present time these are often held to be a group of allegedly "knowledge intensive" high-technology industries, such as ITC, biotechnology and so on. However from a conceptual point of view, in a multi-sectoral economy, the growth rate is a weighted average of the growth of the sectors which comprise the economy (where the weights are shares in output). An empirical examination of the sectoral structure of growth for Europe suggests that growth has a widely-distributed sectoral basis, and that many of the significant sectors are in what are often referred to as "low-tech" industries.

How does this square with the idea that growth depends on innovation? The paper uses *Community Innovation Survey* data to show that innovation also is a sectorally-distributed process. How, then, does this pervasive innovation in "low tech" sectors relate to the creation and use of knowledge? Here the paper uses material from empirical studies of industry-level knowledge bases in the Norwegian economy to suggest that the knowledge bases of apparently low and medium technology industries such as food processing, chemicals, oil and gas, publishing and so on, are in fact deep, complex, science-based and above all systemic (in the sense of involving complex and sustained institutional interactions). The policy point of this is that policy-makers ought to be aware of the industrial structures - and the associated technological knowledge bases - on which growth actually rests, and that this requires a deeper understanding ot the specificity of innovation systems.

1 Diversity and the systems approach to innovation

Any analysis of innovation and growth must face the issue of differences between economies. Everywhere - at the levels of firms, sectors or entire economies - we find heterogeneity. At the micro level, this means among other things that we must be very careful of "representative firm" concepts - we cannot assume that all firms are alike and will respond in similar ways to changed economic or policy signals. At a more macro level, in analyzing economic growth, diversity means that there may be quite different mixes of activities in the growth trajectories of different regions or countries. For economic policy-makers, diversity implies that there may be no general rules with respect to the promotion of innovation and

Figure 1 Gross domestic product by industry 1997



growth, and it is necessary therefore to think in some detail about the specific characteristics of policy contexts.

This paper is about some growth issues related to the specifically Norwegian context. Norway is a small, open economy with many industries which are regarded as traditional, resource-based and low-tech. The basic structure can be seen in Figure 1: in Norway the manufacturing sector is relatively small, and within the manufacturing sector the largest activities are engineering, food and timber products. The "high-tech" sectors (which according to the common OECD definition means sectors spending more than four percent of output on R&D), are very small. So what are the implications of this for economic growth in Norway. The answer to this question depends on the ways in which innovation and knowledge creation relate to growth; we turn now to a more general discussion of this.

2 The Schumpeterian growth concept: radical innovations and structural change

How does innovation relate to economic growth? We turn here to a critical discussion of an approach which is perhaps dominant within modern studies of innovation, namely a disequlibrium growth model based on "creative destruction". The approach can be formulated in different ways, but within it growth is shaped by the irruption of radically new technologies into the economic system. These create new industries which displace existing activities, opening new investment opportunities, and changing the industrial structure. Thus radical technical change, structural change, and growth are part of the same process. One version of this approach permeates economic historiography in the literature on the Industrial Revolution, which is held to derive from steam power, textiles, and so on. In an approach even more influential in innovation theory, deriving from the work of Kondratiev as mediated by Schumpeter, growth tends to be cyclical and epochal. Growth accelerates as new technologies open up investment opportunities, and declines as they are exhausted. In the Kondratiev-Schumpeter framework, radical innovations cluster together, and define eras of accumulation: a steam/textiles era, a vehicles/mass production era, etc. Figure One gives an example of such eras, described in terms of the dominant and emerging technological regimes, which are shaped by the radical breakthoughs.

The most recent systematic formulation of this approach is that of Christopher Freeman and Carlotta Perez, who characterize growth epochs in terms of a dominant "techno-economic paradigm", and of shifts between these paradigms. It should be noted immediately that a policy argument emerges from these approaches, which is that policy-makers should support and reinforce (and if necessary initiate) structural change, investing public resources (or providing incentives for private investment) in the technological capabilities which define the new epoch of growth. The emerging era of our time tends to be defined as the "knowledge-based economy" or the "information society", requiring major new capabilities in IT, telecommunications, and software. More generally the argument is that "high-tech" industries, which in practice means industries investing a relatively high proportion of output in internal R&D, are the growth industries of our age, and should be the focus of innovation policy.

Now it cannot be denied that discontinuous technological change does occur, is associated with structural change, and is associated with the growth process. We can all think of new industries which have emerged, and old ones which have disappeared. What ought to be at issue, however, is whether such processes can

Figure 2 Clusters of pervasive technologies: systems and organization

	1750–1820	1800–1870	1850–1940	1920–2000	1980–
Dominant technology system	Water power, sail shipping, turnpikes, textiles	Coal, sail shipping, canals, iron, steam power, mechanical equipment	Railways, steam ships, heavy industry, steel, chemicals, telegraph	Electric power, oil, nuclear, cars, radio and TV, consumer durables, petrochemicals	Gas, aircraft, space-based telecommunications, information, opto-electronics
Emerging system	Mechanical techniques, coal, stationary steam, canals	Steel, distributed energy supply, telegraph, railways	Electricity, cars, trucks, radio, telephone, roads, chemicals	Nuclear, computers and IT systems, telecommunications, air transport	Biotechnology, AI, IT-telecom integration,
Dominant methods and/or organization	Manufacture, localised enterprise	Centrally managed enterprises, joint stock companies	Standardised parts, M-form corporation	Fordism/ Taylorism, mass production, TNCs.	Quality control, globalised enterprises, de-centralised management

Source: Adapted from M. Nakicenovic, "Diffusion of pervasive systems: a case of transport infrastructures", in Nkicenovic and Grubler (eds) Diffusion of Technologies and Social Behaviour explain growth in any general sense, and therefore whether they offer any reliable guide to useable policy concepts.

There can be no doubt that the Kondratiev/Schumpeter approaches are open to a number of quite basic objections. Firstly, these approaches end to conflate innovation and diffusion - they tend to assume that radical innovations generate rapid impacts. But this assumption is simply not supported in the various historical studies which have been made of some of the allegedly breakthrough technologies. These technologies, when examined closely, take a long time to diffuse and even longer to have an economic impact. (The same point can be argued of IT at the present time - there is simply no body of literature which supports the idea that IT is driving growth at present). Secondly, these new sectors - even when fully diffused and established - do not necessarily contribute to output in a significant way. Obviously the automobile complex of industries grew to be a large element in output, but something like the main hardware electronics/IT sector (ISIC 3825) does not make up more than about four percent of manufacturing output in any OECD economy. So although new technologies and new industries may exhibit rapid growth rates, they are invariably growing from very low levels, and the overall impact may be small. Thirdly, such theories obviously cannot account for growth in countries which do not possess the industries in question. This applies in particular to small economies. Referring back to Figure 2, it is clear that these epochal shifts cannot account for growth in the Nordic area, in Switzerland, in Australia and New Zealand, in the Benelux countries - and these are among the richest economies in the world. These economies are characterized by high growth and high incomes, and are not significantly involved in these allegedly central technologies or industries.

3 Growth patterns: the empirical evidence

To gain a clearer picture of the sectoral composition of economic growth, we can start with the accounting point that the growth rate for any multi-sectoral economy is a weighted average of the growth rates of the sectors, where the weights are the share of each sector in output.

That is to say, in looking at how the overall growth rate is shaped, we need to consider how the different sectors are growing, and then how large those sectors are. If we do this over reasonable time periods we can get a picture of what kind of sectoral growth pattern is really driving aggregate economic growth. EU data shows that it is by no means the case that growth in Europe is driven by a small number of high-tech “knowledge-based” sectors. On the contrary, growth is widely spread across many sectors all of which are fairly closely grouped in terms of average annual percentage growth. Certainly such high-R&D sectors as pharmaceuticals and telecommunications equipment are high growth sectors. But so are many categories of food products, wooden containers, furniture, basic metals, engineering products and so on. In other words, many low-R&D activities are among the high growth sectors.[1] If Norwegian industrial output is disaggregated to product-group level, we get a similar picture.

But we ought to notice also that many of the low and medium R&D-intensity sectors are among the highest in terms of levels of employment and output. Therefore, the contribution of some of these sectors to overall growth is likely to be considerably higher than that of high-R&D sectors where the shares of output (and hence the wights) are much lower.

The point to be made here is that the actual pattern of sectoral growth does not conform either to models put forward by new neo-classical growth theory (in which endogenous knowledge creation is at the fore, if by knowledge creation we mean R&D), not to the Kondratiev/Schumpeter approach which dominates so much of the more innovation-oriented literature.

4 The pervasiveness of innovation

Part of the problem in all this is the view that innovation is something which only or primarily occurs in sectors which are characterized by high levels of R&D input, by significant patenting activity, or by related scientific publication. But in this analysts and policymakers are often far too affected by the availability and quality of indicators. This has been a particular problem for innovation policies, since we have been confined to such sources of data. Without going into detail it is important to remember that these indicators give a very limited view of the nature and extent of innovation activities and outputs. R&D is an input indicator, and not necessarily a good one; patenting data results from a legal process which is to do with appropriability conditions, and indicates at best an invention, not an

[1] See Panorama of EU Industry 1997, Volume 1, Figure 7, (European Commission,:Brussels), 1998

innovation, and so on. These indicators are spector specific, and using them simply privileges some sectors at the expense of others.

A more general indicator is that used in the *Community Innovation Survey*, which in slightly different forms has been carried out in the EU, Australia, Canada, and other countries. This survey collects a very large colume of firm-level data on the introduction of new and technologically changed products, and on the proportion of sales derived from such products. This is an indicator of the rate at which firms change their product mixes, and as such is a direct measure of the flow of innovation; unlike R&D and patent data it can be collected in a relevant way across many sectors.

What does such data tell us about the sectoral distribution of innovation? Here we use data from the Community Innovation Survey, 1992, for four countries: Denmark, the Netherlands, Germany and Norway. Table One shows that a sizeable proportion of firms, rising with firm size, have new products within their sales mix; in this case, products new to the firm which have been introduced to the market within the past three years.

Table 2 looks at the contribution which these new products make to sales within the innovating firms. It is broken down both by industry and size class. The point here is that substantial proportions of sales are coming from new products, across all industries and size classes of firms, in all the countries examined here. Innovation here is not confined to "high-tech" sectors but does indeed appear to be pervasive across sectors. These figures imply rather rapid changes in product mixes in innovating firms.

What kind of conclusion can be drawn from this? One conclusion must be that innovation, in the sense of new product introduction, is widely distributed across

Table 1 Percentages of firms which have some sales of innovative products ("new to the firm"), by size classes (number of employees)

Size classes	Norway	Netherlands	Denmark	Germany
10-19	13	20	na	35
20-49	24	30	35	35
50-99	36	52	46	39
100-199	45	59	58	49
200-499	59	61	43	57
>=500	55	72	67	80

Source: STEP Group

all industrial sectors; it is pervasive, and by no means confined to the so-called "high-tech" sectors of the economy. This leads to the suggestion that the reason why low-tech sectors play such a prominent role in the sectoral distribution of economic growth is not because innovation is unimportant to growth, but rather because these sectors are on the contrary highly innovative. This raises a wider question. Innovation involves learning and the creation of knowledge; it involves the creation of novelty in the various aspects of competence related to product and process development and implementation. If many innovative and growing sectors are relatively low performers of R&D, then how do they innovate: how is knowledge created and used within them?

Table 2. Shares of products "new to the firm" in 1992 sales of those firms which have products new to the firm, by industry and size classes (number of employees)

Industry	NACE	N	NL	DK	G
Mining, oil and gas extraction, energy and water supply	10-14, 40-41	25	22	na	36
Food and beverages, tobacco	15, 16	45	32	48	34
Textiles, wearing apparel	17-18	33	39	147	43
Wood and wood prods, pulp and paper, publishing and printing	20-22	22	27	24	30
Petroleum refining, chemicals, rubber and plastic prods	23-25	27	31	27	51
Other non-metallic mineral prods	26	24	28	123	31
Basic metals	27	10	15	127	33
Fabricated metal prods excl machinery and equipment	28	44	28	29	42
Machinery for prod and use of mechanical power, machine tools	29.1, 29.4	140	29	132	37
General purpose machinery, weapons and ammunition	29.2, 29.6	144	46	31	49
Agricultural and forestry machinery, other special purpose machinery, domestic appliances	29.3, 29.5, 29.7	64	43	34	58
Office machinery and computers, radio, tele and communication	30, 32	56	47	37	77
Electrical machinery and apparatus	31	52	43	29	46
Medical, precision and optical instruments	33	56	42	38	51
Motor vehicles, aircraft and spacecraft	34, 35.3	131	46	138	60
Other transport equipment (excl air and space)	35 excl 35.3	46	36	40	36
Furniture, other manufacturing	36	146	39	41	66

Source: STEP Group

5 Knowledge Production in Medium and Low-R&D Intensity Industries

We turn now to a discussion of the concepts of “knowledge” and “competence” for firms and branches, seeking to clarify the ways in which industries use scientific knowledges and basic research as part of their knowledge bases. The argument here is both theoretical and empirical: we discuss the ways in which basic research results can be used in industry, and then give some empirical rsults from research in Norway, showing how we can understand the knowledge structures of three important Norwegian industries, namely oil and gas, food products, and the chemicals sector. Our fundamental argument is that basic research results flow into industries in indirect ways, via capital equipment, the services of other firms, or services provided by the science and technology infrastructure. Industrial knowledge bases are institutionally distributed. One important result of this “indirectness” is that industries which are apparently “low-tech” can in fact be intensive users of high-grade scientific knowledges.

6 How does scientific knowledge flow into a “low tech” industry?

Flows of knowledge between industries or institutions take two forms, usually known as “embodied” and “dis-embodied” spillovers. Embodied flows involve knowledge which is built in to machinery and equipment. Dis-embodied flows involve the use of knowledge, transmitted through scientific and technical literature, consultancy, education systems, movement of personnel and so on.

The basis of embodied flows is the fact that most research-intensive industries (such as IT, or the advanced materials sector) develop innovative products which are used within other industries. Such products enter as capital or intermediate inputs into the production processes of other firms and industries: that is, as machines and equipment, or as components and materials. When this happens, performance improvements generated in one firm or industry therefore show up as productivity or quality improvements in another. A familiar example is computing, where large decreases in price-performance ratios have their major impact not on the computer industry itself but on computer-using industries (recent research has shown that this is having increasingly large economic impacts). The point here is that technological competition leads fairly directly to the inter-industry diffusion of technologies, and therefore to the inter-industry use of the knowledge which is "embodied" in these technologies. The receiving industry must of course develop the skills and competences to use these advanced knowledge-based technologies.

Consider the fishing sector, a major industry in many countries. Examples of embodied flows in fishing include use of new materials and design concepts in ships, satellite communications, global positioning systems, safety systems, sonar technologies (potentially linked to winch, trawl and ship management systems), optical technologies for sorting fish, computer systems for real-time monitoring and weighing of catches, and so on. Within fish-farming (a very rapidly growing sector, incidentally) these high-technology inputs include pond technologies (based on advanced materials and incorporating complex design knowledges), computer imaging and pattern recognition technologies for monitoring (including 3D measurement systems), nutrition technologies (often based on biotechnology and genetic research), sonars, robotics (in feeding systems), and so on.

The disembodied flows and spillovers are also significant. Underlying these technologies are advanced research-based knowledges. Ship development and management relies on fluid mechanics, hydrodynamics, cybernetic systems, and so on. Sonar systems rely on complex acoustic research. Computer systems and the wide range of IT applications in fisheries rest on computer architectures, programming research and development, and ultimately on research in solid-state physics. Even fish ponds rest on wave analysis, CAD/CAM design systems, etc. Within fish-farming the fish themselves can be transgenic (resting ultimately on research in genetics and molecular biology), and feeding and health systems have complex biotechnology and pharmaceutical inputs. It is clear that a wide range of background knowledges, often developed in the university sector, flows into fishing: mathematical algorithms for optimal control, molecular biology, and a wide range of sub-disciplines in physics for example.

Looked at in these terms, many apparently low-R&D industries, such as the printing and publishing industry (which is one of the largest employment sectors in a number of advanced countries), or service sectors such as retail distribution, can be seen as knowledge intensive sectors, in which firms must learn to manage complex knowledge bases.

7 The knowledge base of an industry

So how can the knowledge base of an industry be understood and described? Clearly all firms operate with some kind of technological knowledge base. However such knowledge bases tend to be complex, in the sense that they involve the articulation of many elements. Here we distinguish between three areas of production-relevant knowledge, namely firm-specific knowledge, sector or product-field specific knowledge, and generally applicable knowledge.

At the firm level, the knowledge bases of particular firms are highly localised, and specific to very specialized product characteristics. We can distinguish between two cases. Firstly, there are firms with one or a few technologies which they understand well and which form the basis of their competitive position. Secondly, there are multi-technology firms, but here also the final product is usually technically very specific in terms of performance attributes and technical characteristics. The highly specific character of these knowledge bases is not simply technical: it is also social, concerning the way in which technical processes can be integrated with skills, production routines, use of equipment, explicit or tacit training, management systems and so on. In terms of the form of knowledge, the relevant technological knowledge base may be informal and uncodified, taking the form of skills specific to individuals or to groups of co-operating individuals. The tacit and localized character of firm-level knowledge means that although individual firms may be highly competent in specific areas, their competence has definite limits. This means, firstly, that they may easily run into problems in innovation which lie outside their area of competence, and secondly that their ability to carry out search processes relevant to problems can also be limited; this they must be able to access and use knowledge from outside the area of the firm when creating technologies.

Then there are knowledge-bases at the level of the industry or product-field. At this level, modern innovation analysis emphasizes the fact that industries often share particular scientific and technological parameters; there are shared intellectual understandings concerning the technical functions, performance characteristics, use of materials and so on of products. Of course this knowledge base does not exist in a vacuum. It is developed, maintained and disseminated by institutions of various kinds, and it requires resources (often on a large scale).

Finally, there are widely applicable knowledge bases, of which the most important technically is the general scientific knowledge base. This is itself highly differentiated internally and of widely varying relevance for industrial production; but some fields - such as molecular biology, solid-state physics, genetics or inorganic chemistry - have close connections with major industrial sectors. Although it is important not to overemphasise the role of scientific knowledge in modern industrial development, or to presume that there is a one-way connection between science and technology, the connections of course exist and are very important.

8 Identifying the industry-level knowledge base[2]

Inwork within the STEP Group on knowledge bases, we seek to map knowledge bases by identifying and describing the following basic aspects of industrial production:

- First, the key activities in the industry in terms of technical phases of production. What are the main technical components of production activity within the sector concerned? What must a firm do to be a viable operator in the industry?
- Second, the key techniques - meaning capital inputs, equipment, instruments and production routines - being utilized to perform these activities. What are the techniques which the firm must master in order to be able to undertake the activities described above?
- Third, the knowledge bases - in terms of engineering and scientific knowledges - supporting these techniques. What are the codified knowledges with which the technical operations are designed, analyzed, and produced?
- Fourth, the institutional framework. What are the organizational forms - in terms of companies, research institutes, universities and so on - through which these knowledges are produced and disseminated? Concretely, who develops the relevant knowledge inputs, and on what resource basis?

[2] This and the following section draws on work within the STEP Group by Keith Smith, Espen Dietrichs, Trine Knudsen, Tor Egil Braadland and Thierry Lamoury

Within the STEP group, studies have been made of a number of industry level knowledge bases. These include hydropower, food products, fisheries and fish-farming, medical equipment, the graphics industry, the engineering sector, bulk and fine chemicals, and oil and gas. The following section shows some of the results for oil and gas, as an illustration of what kinds of general issues emerge from these kinds of studies.

9 Knowledge bases (i): the oil and gas sector

Figure 3a-c, which presents petroleum techniques and related, but separate R&D institutions, gives an example of this approach. The different divisions of the petroleum sectors, into *phases, key activity, technique and knowledge base* are based on a variety of sources. The acronyms refer to institutions within the Norwegian science and technology infrastructure - for details see Appendix 1.

Figure 3a Key activities, techniques, knowledge bases and research institutions in different phases of the Norwegian offshore sector. Field exploration phase

Key activity	Technique	Knowledge base	Research institution
Collecting geological data	Operating marine vessels	Navigation	NTNU-TC
	Seismic acquisition	Seismology	SINTEF TI, UiO-G, UiB-ISEP, NTNU-DoT, NORSAR, Statoil
	Drilling	Engineering / material technology	SINTEF Ch, SINTEF CEE, SINTEF MT, SINTEF U, Molab, UiO-Ch, UiB-P, HiS-MMT, NORUT t, MBS, MARINTEK, NTNU-GE, RF, Statoil
		Physics	SINTEF CEE, SINTEF MT, UiO-G, UiO-Gp, UiB-ISEP
		Geology	UiO-G, UiB-G, IKU, HiS-DPT, HiS-MMT, IKU, NGU, NP, RF, Statoil
Analyzing geological data	Seismic interpretation	Seismology	SINTEF TI, UiO-G, UiB-P, UiB-ISEP, NORSAR, Statoil
	Geological interpretation	Geology	UiO-G, UiB-G, Statoil, IKU, HiS-DPT, MMT, IKU, NGU, NP, RF
		Geophysics	UiO-G, UiO-Gp, UiB-G, IKU, NTNU-P, NGU, NP, Statoil
		Geochemistry	UiO-G, NGU

The key points are of course the wide array of knowledge inputs across many activities, and the very substantial number of science and technology infrastructure institutions which are involved in generating, supplying or maintaining them. In this figure we include only specifically Norwegian infrastructural institutions - we are not including specialized suppliers, or international institutions.

Figure 3b Key activities, techniques, knowledge bases and research institutions in different phases of the Norwegian offshore sector. Field development phase

Key activity	Technique	Knowledge base	Research institution
Engineering and manufac turing the inst- allations	CAE/CAD/CAM (cybernetics)	Industrial instrumentation (cybernetics)	UiB-P, HiBu-ETC, SINTEF AM, SINTEF TI, MPP, CMR, IFE, MBS, SINTEF EC, NTNU-DTC, HiBu-ETC, HiS-EC
		Engineering/ material technology	SINTEF Ch, SINTEF CEE, SINTEF MT, SINTEF U, Molab, UiO-Ch, UiB-P, HiS-MMT, NORUT t, MBS, MARINTEK, NTNU-GE, RF, NORSAR, NAT, HiM
		Physics	SINTEF CEE, SINTEF MT, UiO-G, UiO-Gp, UiB-ISEP
		Geology	UiO-G, Statoil, UiB-G, IKU, DPT, HiS-MMT, NGU, NP, RF, SINTEF AM, NG
		Climatology	SINTEF AM, SINTEF E, MARINTEK, UiO-Gp, NTNU-MH, NORUT, IT, DNMI
		Mechanics	SINTEF Ch, SINTEF AM, UiO-P, DPT, RF, HiM
		Machinery	MARINTEK, NTNU-DTC, HiS-MMT
	Construction, mechanics, electronics, electricity	Engineering/ material technology	SINTEF Ch, SINTEF CEE, SINTEF MT, SINTEF U, Molab, UiO-Ch, UiB-P, HiS-MMT, NORUT t, MBS, MARINTEK, NTNU-GE, RF, NORSAR, NAT, HiM
		Geometry	SINTEF AM
		Subsea technology	NTNU-MPP, HiS-MMT, FFI, MARINTEK, Nutec, Statoil
		Optimisation	SINTEF AM
	Machine techniques	Mechanical engineering	SINTEF Ch, SINTEF AM, UiO-P, HiS-DPT, RF
		Electronics	SINTEF EC, UiB-P
		Subsea technology	NTNU-MPP, Statoil, HiS-MMT, FFI, MARINTEK, DNV, Nutec
Installation	Mooring	Cybernetics	MARINTEK, DNV
		Geometry	SINTEF AM

Figure 3c Petroleum production phase

Key activity	Technique	Knowledge base	Research institution
Maintenance	Construction, mechanics, electronics, electricity	Engineering/ material technology	SINTEF Ch, SINTEF CEE, SINTEF MT, Statoil, SINTEF U, Molab, UiO-Ch, UiB-P, HiS-MMT, NORUT t, MBS, MARINTEK, NTNU-GE, RF, DNV, NAT, HiM
		Geometry	SINTEF AM
		Subsea technology	NTNU-MPP, HiS-MMT, FFI, MARINTEK, Nutec, Statoil
		Optimisation	SINTEF AM
	Machine techniques	Mechanic engineering	SINTEF Ch, SINTEF AM, UiO-P, HiS-DPT, RF, HiM
		Electronics	SINTEF EC, UiB-P
		Subsea technology	NTNU-MPP, HiS-MMT, FFI, MARINTEK, Statoil, Nutec
		Cybernetics	SINTEF EC, HiS-DTC, HiBu-ETC, HiS-EC
Surveillance	Monitoring / well logging/ production	IT -engineering	SINTEF EC, SINTEF TI, MBS, MARINTEK
		Computer imaging	SINTEF Ch, SINTEF EC
	Logging	Electronics	SINTEF EC, UiB-P
		MR	UiB-Ch
		Optics	SINTEF EC, UiB-P
		Acoustics	SINTEF Ch, SINTEF TI, UiB-P, NTNU-DoT, CMR, IKU
		Wave analysis	SINTEF AM, SINTEF CEE, UiO-Gp, UiO-Gp, NTNU-MH
		Climatology	SINTEF AM, SINTEF E, MARINTEK, UiO-Gp, NTNU-MH, NORUT, DNMI
Well handling, reservoir	Reservoir evaluation technology and transportation	Geology	SINTEF AM, UiO-G, HiS-DPT, HiS-MMT, IKU, NGU, NGI, RF, Statoil
		Geophysics	SINTEF CEE, SINTEF MT, UiO-G, UiO-Gp, UiB- ISEP, Statoil
		Geochemistry	UiO-G, NGU, Statoil
	Gas and water	Geochemical engineer.	IKU, RF, IFE, NTNU-DIC, HiS-DPT, AQUA
	Injection	Numerical simulation	SINTEF Ch, SINTEF AM, HiS-DPT
	Storage	Engineering/material technnology	SINTEF CEE, MBS
	Processing, separa-tion/streaming tech.	Geochemistry	SINTEF Ch, SINTEF AM, UiO-P, HiS-DPT, RF, CMR, IFE, UiB-C, NTNU-DIC, MARINTEK, Statoil
	Transportation / Pipelines	Engineering/ material technology	MBS, NAT, DNV, HiM
		Geochemistry	SINTEF E
	Refining	Geochemistry	SINTEF Ch
Safety and environment	Life and Environmental protection	(Varieties)	HiS-DPT, HiS-MS, RF, SINTEF Ch, SINTEF AM, IKU, SINTEF UNIMED, SINTEF E, HSH-DE, CMR, UiO-G, NORUT, NERSC, NIVA, RF, DNV, NORSAR, NAT, Nutec, AQUA, Statoil

10 General industry knowledge bases

The results which have been illustrated from the oil and gas sector can be generalized: they apply across more or less all sectors of the Norwegian economy. For example, the food industry is often regarded as very low-tech because of a very low level of internal R&D, but it has a substantial array of indirect knowledge inputs. The core knowledge areas of the food processing industry are food science, including food related chemistry, biology and physics, and food technology including biotechnology, electronics, instrumentation and engineering. Despite the fact that this is an industry with relatively low levels of internal R&D, it might well be claimed that this is one of the most knowledge-intensive sectors of the entire economy. Presumably this is not unrelated to the fact that many of the sub-sectors of the food industry are rapidly growing at the present time.

11 Conclusion

While we cannot deny that new sectors emerge within the economy, and that some sectors disappear, this does not account for the processes of growth which actually occur. The growth trajectories of the advanced economies rest far more on such sectors as engineering, food, wood products, vehicles and so on, than on allegedly radical new "growth" sectors as ICT or biotech. ICT has of course grown rapidly, but from a very low base, and with a very low share of output. Growth within these sectors is certainly innovation-based, and moreover it rests on complex and deep knowledge bases, which from time to time are subject to discontinuous change. One suggestion which emerges from all this is that growth is primarily based not on the creation of new sectors but on the internal transformation of sectors which already exist. This internal transformative capacity rests, in turn, on complex innovation systems which create, distribute and maintain advanced (often basic scientific) knowledge.

We could sum up the argument here as follows:

- Economic growth is sectorally distributed across the industrial structure, and there is no particular industrial structure which is conducive to growth; on the contrary, countries with industrial structures oriented to so-called low and medium-tech industries can and do grow rapidly.

- So-called low and medium-tech are invariably innovative industries in the sense that they develop and market new products in a continuous fashion
- Most so-called low-tech sectors are intensive in their use of scientific knowledge – industries such as food production, machinery, printing and publishing, wood products, and a range of services, have significant indirect science inputs. The depth and complexity of industry knowledge bases are not linked to their direct R&D performance.
- These science inputs are supported by complex, indirect links with universities, research institutes and supplier companies. Thus “low tech” industries are frequently part of “high-tech” systems, and policy-makers should be aware of their significance for growth.

If there is a policy lesson here, it is that policy-makers need an empirically formed understanding of the systems in which they operate, and that before seeking to change industrial structures toward some alleged “knowledge-intensive” growth pattern, they would do well to understand the growth performance and possibilities of the diverse systems which they actually do have. The Norwegian economy is based on a number of sectors which are predominantly low-tech. But they are rapidly growing and innovative, precisely because they are knowledge intensive.

Appendix 1 Science and Technology Infrastructure Institutions in Norway

Abbreviations

Universities and colleges

HSH-DE = Department of Engineering, College of Stord/Haugesund
HiM = College of Molde/Møre Research (Møre and Romsdal Research Foundation)
HiS-DPT = Department of Petroleum Technology, College of Stavanger
HiS-EC = Department of Electronics and Computing, College of Stavanger
HiBu-ETC = Department of Electronics and Technical Cybernetics, College of Buskerud, Kongsberg
HiS-MMT = Dep. of Machinery and Material Tech., College of Stavanger
HiS-MS = Department of Mathematics and Science, College of Stavanger,
NTNU = The Norwegian University of Science and Technology, Trondheim
NTNU-DIC = Department of Industrial Chemistry, NTNU, Trondheim
NTNU-DoT = Department of Telematics, NTNU, Trondheim
NTNU-GE = Department of Geotechnical Engineering, NTNU, Trondheim
NTNU-MH = Department of Marine Hydrodynamics, NTNU, Trondheim
NTNU-MPP = Department of Marine Project Planning, NTNU, Trondheim
NTNU-P = Department of Physics, NTNU, Trondheim
NTNU-TC = Department of Technical Cybernetics, NTNU, Trondheim
UiB-Ch = Department of Chemistry, University of Bergen,
UiB-G = Department of Geology, University of Bergen,
UiB-Gp = Department of Geophysics, University of Bergen,
UiB-ISEP = Department of Solid Earth Physics, University of Bergen,
UiB-P = Department of Physics, University of Bergen
UiO-Ch = Department of Chemistry, University of Oslo
UiO-G = Department of Geology, University of Oslo,
UiO-Gp = Department of Geophysics, University of Oslo,
UiO-P = Department of Physics, University of Oslo

Institutes and private institutions

AQUA = AQUATEAM - Norwegian Water Technology Centre, Oslo
CMR = Christian Michelsens Research AS, Bergen
DNMI = Norwegian Meteorological Institute, Oslo
DNV = Det Norske Veritas Research AS
FFI = Norwegian Defence Research Establishment, Horten
IFE = Institute for Energy Techniques, Oslo
IKU = Continental Shelf and Petroleum Technology Research, Trondheim
MARINTEK = Norwegian Marine Technical Research Institute, Trondheim
MBS = The Norwegian Institute for Masonry and Concrete Research, Oslo
Molab = SINTEF Molab, Mo
NAT = Norwegian Applied Technology
NERSC = Nansen Environmental and Remote Sensing Centre, Bergen
NGI = Norwegian Geotechnical Institute, Oslo
NGU = Geological Survey of Norway, Trondheim
NIVA = Norwegian Institute for Water Research, Oslo
NORSAR = The Norwegian Seismic Array, Oslo
NORUT = NORUT IT, Tromsø
NORUT t = NORUT technology, Narvik
NP = Norwegian Polar Institute, Oslo
Nutec = Norwegian Underwater Technology Centre, Bergen
RF = Rogaland Research, Stavanger
SINTEF = The Foundation for Scientific and Industrial Research
SINTEF AM = SINTEF Applied Mathematics, Trondheim/Oslo
SINTEF CEE = SINTEF Civil and Environmental Engineering, Trondheim
SINTEF Ch = SINTEF Chemistry, Trondheim /Oslo
SINTEF E = SINTEF Energy, Trondheim
SINTEF EC = SINTEF Electronics and Cybernetics, Trondheim/Oslo
SINTEF MT = SINTEF Materials Technology, Trondheim /Oslo

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