Innovation by co-evolution in natural resource industries – the Norwegian experience

By Bjørnar Sæther, Arne Isaksen and Asbjørn Karlsen

PUBLISHED IN GEOFORUM 42 (2011) 373-381

Abstract

Some resource-based economies become wealthy while others stay poor and Norway belongs to the first category. This paper argues that part of the answer to why Norway has managed to benefit from its rich natural resources is found in the formation of a well-functioning national innovation system. The paper integrates the innovation system approach with a historical approach through the concept of co-evolution. The empirical study investigates how innovation systems evolve in natural resource industries through analysing the co-evolution between industry, knowledge organisations and national policy in the Norwegian aluminium and petroleum sectors. Parallels are found in the development of these two sectors, which are: i) the deliberate use of concession laws to seize value creation and technological development from foreign direct investments, ii) the establishment and prioritisation of state-owned companies and iii) the more or less intentional formation of a national innovation system. The paper points to the relevance of analysing the historical evolution of national innovation systems to understand the creation of their specific path-dependent characteristics, to analyse how policy influences the creation and working of innovation systems, to use a multilevel approach in studies of innovation systems and to consider how innovation processes in different industries are linked in value chains and through knowledge flows.

Kew words: innovation systems, co-evolution, natural resources, petroleum, aluminium, Norway

1. Introduction

There is a growing interest among scholars in the role of natural resources in economic development. Some resource-based economies are among the wealthiest nations, such as Canada, New Zealand, Finland and Norway (Smith, 2008), while resource-based economies in the third world, on the other hand, often stay poor (Mehlum et al., 2006). Influential economists have based their models on a 'manna from heaven' approach, which means that capital and labour are not used in the natural resource sector (Sachs and Warner, 1997, p. 6). By examining the dynamics and development of resource-based economies we find the 'manna from heaven' approach unproductive. The extraction of resources will influence the economy by shifting labour and capital towards such activities, by offering higher wages resource extraction will attract well educated workers. Income from resource extraction will stimulate demand from the service sector and increase wages, which may lead to a "crowding out" effect as traditional export oriented industries looses their competitive advantage (Cappelen and Mjøset, 2009). This might not be a problem as long as there is a resource boom, but after the boom the economy could face a difficult situation. This occurred in Holland and is known as the "Dutch disease". Even though Norway so far belongs to the well performing resource based economies, the country could face a future case of Dutch disease with a steady fall in oil production. A crowding out effect of traditional industries can be observed, but so far this effect has been counterbalanced by growth in the petroleum sector and in supplies of goods and services to this sector. This pattern of resource based growth is investigated in this paper with an emphasis on institutions promoting innovation.

Wealthy, resource-rich countries have in general avoided an *enclave* type of industrial development where the natural resource sector is isolated from the rest of the economy. Instead the natural resource sector is linked to other parts of the economy (Hirschman, 1977). The functioning of these linkages is dependent on institutions, in the meaning of common norms, routines and rules (Edquist, 2005). Institutions promoting innovation and dynamic growth have been decisive for resource-rich countries that experience successful economic development (Cappelen and Mjøset, 2009; Mehlum et al., 2006; Wright and Czelusta, 2003). This paper argues that institutions stimulating interaction between actors in innovation systems are among the key factors that decide whether natural resources are turned into a curse or into economic development. One reason why some countries are wealthy *and* resource rich is, thus, because of complex innovation systems that support the development of resource-based industries (Fagerberg et al., 2009; Wicken, 2008). Knowledge flows into the resource-based industries from the rest of the economy, and the innovation systems stimulate knowledge creation and innovation activity in the natural resource industries. The resource-based industries are demanding buyers of goods, services and technology from other parts of the economy and the knowledge infrastructure, which in some cases have spurred a cumulative growth process at a regional and national level. Thus, in the case of Norway, Grønning et al. (2008, p. 282) maintain that affluence gained through low-technology resource extraction reflects 'the existence of innovation-intensive technological trajectories within sectors such as mechanical engineering, engineering consultancy and suppliers to the aquaculture sector'. The natural resource-based industries in Norway have been highly innovative for decades, 'drawing on domestic innovation, [and] technology transfer from foreign sources' (Fagerberg et al., 2009, p. 9). While mainly supporting such views, Narula (2002) also warns against a danger of systemic and technological lock-ins of the Norwegian systems of innovation (SI) in mature resource-intensive sectors: 'Norwegian firms are ‘locked-in’ to the SI, and this restricts their activities, both on a technological and an organisational sense’ (Narula 2002, p. 811). Narula maintains that the Norwegian SI has favoured national champions in mature resource-based industries such as the company Hydro within aluminium. The favouring of such companies leads to a lock-in around mature sectors, and a consequence according to Narula is that the SI does not meet the needs of younger and smaller firms in more technology-intensive, science based sectors.

An innovation system approach has been developed over two decades in order to study cumulative growth processes at a regional and national level (Cooke, 2004; Lundvall et al., 2002). Such studies have often been snapshots of technologically dynamic industries such as biotechnology and information and communication technologies. Less attention is paid to how innovation systems have evolved. Natural resource industries are not considered as technologically dynamic within a Schumpeterian approach, and have subsequently received less interest within innovation studies (Von Tunzelmann and Acha, 2005). This paper argues that a broad innovation system approach is useful in studies of technological and organisational changes in natural resource industries, and that studies should focus on how industries have evolved over time, and on some unique aspects of innovation processes in natural resource industries. The formation and historical development of the Norwegian aluminium and petroleum sector and related knowledge institutions is studied with regard to critical incidents and interaction between sectors and institutions. The national knowledge infrastructure and learning and remembering at the political level are considered as decisive for a successful development of these two sectors. Dynamism at the regional level has also resulted in six to eight regional clusters that are closely integrated with the petroleum and aluminium sectors. The primary *research question* guiding our analysis is which mechanisms have been decisive in creating apparently working innovation systems within the aluminium and petroleum industries in Norway, and second what more general theoretical lessons that can be drawn from the study of these two natural resource sectors.

The next section discusses the theoretical framework based on the innovation system approach, the concept of co-evolution and some unique aspects of innovation activity in the natural resource industries. Then the evolution of the innovation system in the Norwegian aluminium and petroleum sectors is examined. The analysis draws on existing studies of the sectors and on the authors' own empirical study of the sectors (cf. Authors, 2008). The conclusion sums up the findings and discusses theoretical lessons.

2. A broad innovation system approach

The innovation system approach conceptualises innovation activity as carried out through a stable network of private and public actors. Thus, a central finding in innovation research is that 'firms seldom innovate in isolation' (Fagerberg et al., 2005, p. 180). The actors within innovation systems constitute two subsystems (Cooke et al., 2000, pp. 104–105). The first consists of firms in the industrial sector in question, including their upstream and downstream activities. The second subsystem includes the knowledge infrastructure of education and research institutions as well as technology centres, science parks, incubators etc. The systems of innovation approach by 'the Aalborg school' highlighted user–producer interaction as vital for innovation, and cooperation between the actors is underpinned by an institutional framework of informal rules of conduct, government regulations and policy instruments (Edquist, 2005; Lundvall et al., 2002). Some actors enter into long-standing cooperation characterised by interactive learning in an atmosphere of mutual understanding and common rules. The concept of an innovation system is thus based on the idea that the overall innovation performance of an economy depends on how firms utilise the experience and knowledge among other actors and mix this with internal capabilities (Gregersen and Johnson, 1997).

Innovation systems can further be defined in a narrow and a broad way (Asheim, 2007; Lundvall, 2007). The narrow definition includes R&D activities at universities, research institutes and firms' R&D departments. This definition can be linked to the science, technology and innovation (STI) mode of innovation. Innovation activity is science-based, involving R&D departments in firms in collaboration with universities and R&D institutes (Jensen et al., 2007). The broad definition of an innovation system includes all the actors and activities that affect learning, knowledge creation and innovation. Thus, Edquist defines systems of innovation as 'all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion and use of innovations' (Edquist, 2005, p. 183). The broad definition relates to the doing, using and interaction (DUI) mode of innovation. Innovation activity is experience-based and competence is built through on-the-job training and education, rather than on R&D (Jensen et al., 2007).

Innovation systems are classified according to the context considered most important for the main actors and institutions (Wicken, 2008). The important context can be defined by geography (national and regional systems), industrial sectors (sectoral systems) or generic technologies (technological systems). Firms are often part of several of these innovation systems; however, one type of system may be the most relevant to specific firms. A number of global competitive Norwegian firms are part of regional innovation systems, but depend on the Norwegian sectoral innovation systems within the oil and gas and the maritime sector for R&D cooperation (Author, 2009). Thus, different types of innovation systems may partly overlap. Sectoral characteristics influence the knowledge infrastructure, institutions and policies at the national level, while the sectoral structure of a national economy is influenced by the latter (Fagerberg et al., 2009). A sectoral innovation system can over time become embedded in a national innovation system. Differences in national innovation systems lead to different innovation performances between nations (Nelson, 1993). The national level is particularly important when it comes to the policy dimension; 'As long as national states exist as political entities with their own agendas related to innovation, it is useful to work with national systems as analytical objects' (Lundvall et al., 2002, p. 215).

The concept of a regional innovation system (RIS) is geared towards the study of informal cooperation, knowledge spillovers and the exchange of tacit knowledge between co-located partners. Sectoral and technological innovation systems focus on the technology, the knowledge base and the institutional context in which firms act (Malerba, 2004, p. 15). Innovation processes are affected by industrial sectors, and firms that face similar technologies are seen to 'share some common behavioural and organizational traits and develop similar range of learning patterns, behaviour and organizational forms' (Malerba, 2004, p. 15). In this study, innovation systems at the national, sectoral and regional levels are significant, but particularly the intersections between them, which also indicate the dynamics of innovation systems.

Path dependency and co-evolution

The literature on innovation systems discusses the working of current systems rather than how the systems are created and changed (Lundvall, 2007). The innovation system approach is part of a wider institutional perspective that broadly defined understand routines as 'programmatic' (Nelson, 2002). The concept of path dependence is part of this perspective and underlines the importance of a historical and dynamic approach to the study of innovation systems. Path dependence often refers to a situation where a system (industry, technology, regional economy) is marked by inertia. However, a key insight within institutional and evolutionary economics is the capacity of the economy to transform itself, in particular through knowledge generation and the accumulation of capabilities through time; 'institutions and past trajectories channel change, at the very same time they also enable adaptation and the launch of new paths' (Martin and Sunley, 2010, p. 75). Institutions and human resources supporting one industry can represent critical capabilities for the creation and growth of other industries.

Path dependence often involves the co-evolution of several arenas – the economic, technological, institutional and socio-cultural. Co-evolution refers to converging processes between an evolving unit and its environment and a mutual adaptation of the two. A definition of the term is suggested; 'Two evolving populations co-evolve if and only if they both have a significant causal impact on each other's ability to persist' (Murmann, 2003, p. 210). The co-evolution of technology and industrial structures were highlighted in early studies, while later research has studied how private and public organisations, public programmes and policies have co-evolved with technology and industry (Nelson, 1995). The co-evolution of industry and the university system is a precondition for the formation of functioning innovation systems. Causal processes connecting industry and university and how they influence each other's evolutionary trajectories have to be analysed.

Co-evolution is operationalized along three bidirectional causal links between firms and universities. First personnel are exchanged between industry and university and flows of skills and knowledge takes place, second academics are likely to enter into a commercial relationship with a firm, and third industries compete for favourable regulations and public support whereas academic disciplines compete with other disciplines for access to limited R&D funding. Academics and industrialists with a common interest in lobbying government for support can enter into a coalition. An indirect relationship may exist as government takes actions to strengthen both the industry and the relevant academic discipline (Murmann, 2003, p. 212). Government funding of research is vital in institutionalising university-industry interaction, and mutual development between industry, universities and government bodies reinforces the working of innovation systems (Wolfe, 2005).

Innovation in resource-based industries

Do innovation systems in resource-based industries have any unique characteristics? Natural resources are not fixed entities but 'defined by man' (Rees, 1990). The key innovations forming the basis for a natural resource industry allow a resource to be used for a particular purpose. The Otto engine is an example of a radical innovation using oil for its operation, and a complete system for exploration, production and distribution of oil was established after 1880 (Freeman and Louca, 2001). The easily accessible natural resources are, as a rule exploited first and the cost of exploration and development are rising. A trade-off exists between rising costs and innovations: 'There is a constant tension between forces which raise extraction and refining costs – the depletion of high-grade deposits – and those which lower such costs – discoveries of newer technological processes and materials' (Perman et al., 2003, p. 480). Both extensive and intensive strategies can be used to increase the supply of a resource. Extensive expansion is based on using the established technology in a new location in which the procedure of exploration and production is replicated. Intensive expansion includes radical and incremental innovations in existing technology. This may lead to a higher recovery rate, e.g. the rate has increased from 20 to 50 per cent in some petroleum fields.

Studies of resource-based industries in the US indicate that the depletion of easily accessible reserves has resulted in technological progress (Simpson, 1999). New technology is, however, also the key to discovering new resources in less accessible locations unavailable with previous technologies. The search for additional resources of e.g. oil and minerals in low-grade deposits and in harsh environmental conditions are not only dependent on the available technological level in the resource-based industries themselves, but also among the supplier industries constructing equipment for mining and oil production. Co-evolution between the natural resource industry and its suppliers is thus a key point, the petroleum industry could not exist without its suppliers and vice versa. Given the dependence on new technology for the exploration and development of additional natural resources, analyses of innovation activity in resource-based industries have to include the technology suppliers.

Analyses of innovation activities in resource-based industries are a key to understanding growth processes in regions and nations dominated by such industries, which is the case for Norway. Politics and institutional innovation influence the path-dependent character of the Norwegian national innovation system. The economic dynamism caused by natural resource-based industries depends on knowledge spillover effects between other sectors of the economy (Smith, 2008; Wicken, 2008). The realisation of spillover effects, however, rests on a number of political and institutional preconditions. National sovereignty over natural resources and political power to secure the regional or national capture of value are instrumental in order to embed a sectoral innovation system nationally. A public licensing of the right to exploit natural resources is a policy means to create linkages between the natural resource industries and other sectors of the economy. Within a licensing system applicants have to specify how their activities will support national suppliers and knowledge providers (Engen, 2009). Our study of the aluminium and petroleum sectors in Norway analyses the historical development of the relevant innovation systems and on political decisions having stimulated the creation and working of the systems. Aluminum production was established as an export industry about 100 years ago, and not only the economic significance, but also the technological and political learning processes in the industry make it an interesting case. We argue that the learning process was institutionalized and actively informed the regulation of the petroleum industry emerging in the 1970s.

Figure1 in here

Figure 1 illustrates the long term development of the two Norwegian industrial sectors analyzed in this paper. The petroleum sector has since the 1980s become the most important resource based industry, and has counted for 55-60 percent of total exports the last five years. The petroleum sector is an interesting case in any analysis of innovation in natural resource industries in Norway, not only because it's economic importance, but because the significant technological and political learning processes within this industry.

3. Pioneering an innovation system within aluminium

Aluminium, petroleum and their supplier industries represent a substantial part of manufacturing jobs and value creation in Norway. Aluminium amounts to about 4 per cent of total exports the last five years. The Norwegian aluminium sector with about 4,000 employees is concentrated in energy-intensive primary production based on the exploitation of domestic hydroelectric power. Seven plants are historically located close to the hydroelectric power plants in rural areas and are the cornerstones of single industry towns. As the vertically integrated aluminium companies based in Norway have most of their fabrication abroad, there is limited downstream fabrication in Norway (Author, 2008). A major exception is the automotive component industry located at Raufoss.

Radical innovations in the early twentieth century within turbine technology made it possible to exploit large amounts of hydro power available along the western coast of Norway. Access to cheap energy and good harbour facilities relatively close to the emerging European market attracted foreign direct investments (FDI) in the metallurgical and chemical industries. Norway became independent in 1905 and there was a political will to build the nation. The exploitation of hydro power became tightly regulated through the Concession Act in 1911. The concession act was one means to obtain national control over vital natural resources and to fulfil national development ambitions. Since foreign companies did not have immediate access to Norwegian waterfalls, the state was in a position to negotiate the terms of investments and industrial activities. During the next decades the application of the act was, however, liberal in order to attract FDI. As there were no Norwegian industrialists with experience from aluminium production, foreign aluminium companies were welcomed-they had access to technology, overseas bauxite ores and markets. There was a lack of capital in Norway, which at that time was among the poorer countries in Europe. The concession act, however, gave the government a position to set premises for FDI after the Second World War, and the act became vital in the government's role of linking foreign and national companies through barter agreements and joint ventures. Through cross company collaboration and increasing national ownership there were knowledge spillover as well.

After 1945 aluminium production grew fast, partly due to an industrial policy targeting this sector in order to modernize the economy (Sandvik, 2008). For three decades a mixture of state ownership and joint ventures between Norwegian, Canadian, Swiss and US companies increased the national control of the industry. In the 1970s the state-owned company ÅSV strived for autonomy and led way in building national R&D capacity through locating complementary R&D units at its two Norwegian plants. ÅSV started to collaborate with the Norwegian Institute of Technology, the Institute for Energy Technology in Oslo and Sintef in Trondheim. Sintef was established as a “Society for industrial and industrial research” in 1950 at the Norwegian Institute of Technology. Research still reflects the disciplinary profile of its partner, the publicly owned Norwegian University of Science and Technology, which is the successor of the Norwegian Institute of Technology. Sintef has grown into the largest research contractor in Scandinavia with about 2000 employees, of which 1450 are located in Trondheim in mid-Norway.

The company Hydro was established in 1905 as a producer of fertilizers based on Norwegian inventions and easy access to hydro power. In the post war period it became a partly state owned company which recently has concentrated on aluminium only. Employing 19,000 people in 40 countries, Hydro is one of Norway’s industrial champions. Since the 1960s Hydro has operated the only vertically integrated aluminium plant in Norway, and the nearby competence centre served the fabrication of aluminium products (Sandvik, 2008). When the government forced ÅSV to merge with Hydro in the 1980s, the companies’ R&D units were integrated. Hydro still has three R&D units close to production plants, which makes full-scale experiments and collaboration with operators possible. A co-evolution of the aluminium sector and national knowledge organisations started in the 1980s with closer relations between industry, the trade association, unions, the social democratic party, research institutes and universities (Moen, 2009). The aluminium sector has a strong position in industrial policy not at least through the trade association representing companies in energy intensive industries (Midtun, 2007). Industry leaders and leading Labor party politicians held crossing positions in

ÅSV and the Research Council. These networks were probably activated in order to influence national research policy and government was successfully lobbied for financial support to education and applied research programmes in the interests of the aluminium industry (Author, 2008).

As the national control of the aluminium industry increased until the 1980s, the national R&D capacities also improved. The dependence on foreign technology and competence was reduced as industry recruited graduate engineers and PhD candidates from the Norwegian Institute of Technology. The aluminium industry was prepared for R&D since managers and key personnel were graduate engineers with knowledge, networks and motivation for research (Author, 2008). As ÅSV and later Hydro employed R&D staff, they collaborated with the universities and the research institutes and were able to absorb knowledge. A professional community of technologist and scientist with common educational background and references co-evolved across organizational boundaries. Co-evolution of industry, university and research institutes was reinforced through mobility of professionals between the three spheres.

Innovation activity was directed to the improvement of production processes, in order to reduce the consumption of energy and emission of fluorides. Later innovations included quality improvements of alloys and fabricated products, and upgrading through incremental innovations has been important for the competitiveness. Integrated innovation along the value chain has involved Hydro's fabrication abroad. During the 1990s Hydro introduced a new generation of research programmes in which industrial-political networks were activated to influence the design of user-driven R&D projects funded partly by the Research Council of Norway (Author, 2008). This brought industry, research institutes and universities into closer contact. The government played a set of significant roles being responsible for higher education and public research, as a dominant shareholder of Hydro and as a manager of energy resources and environmental regulations. This exemplifies the crucial role political involvement has in the formation of a national innovation system in natural resource industries.

Since Hydro acquired the German Vereinigte Aluminiumswerke in 2002, Hydro has become the world's third-largest vertically integrated aluminium company. The doubling of size has been possible due to years of high performance of an international competitive company. The national innovation system has strengthened the company's capability to expand internationally and currently Hydro has R&D units in the US and Germany, but its major R&D capacity is still located in Norway. The national character of R&D in the aluminium industry is explained by the importance of input cost and less need to establish significant R&D capacity close to customers (Narula, 2002). Although the national role in the innovation system is somewhat weakened during the first years of the new millennium due to internationalisation and capital concentration, it is still evident. Two Alcoa plants located in Norway rely to some extent on Alcoa's international R&D capacity, but still collaborate in R&D projects based in Norway. The universities, research institutes and the Research Council have a national agenda, even if university research is internationally oriented as well. The close and long-lasting interaction between Hydro, the Norwegian University of Science and Technology and Sintef are particularly prominent. They constitute dominant components in a national innovation system.

The fabrication of aluminium products at Raufoss

A cluster of automotive component firms at Raufoss represents the most significant example of downstream fabrication of aluminium products in Norway. This cluster supports points made on the role of government policies in obtaining market outlets and the role of national knowledge organisations supporting technological development. Raufoss is located 100 km north of Oslo with 4,000 manufacturing jobs. The core of the manufacturing industry in Raufoss is five large firms producing components in aluminium and other light-weight materials for the global automotive and military industry (Onsager et al., 2007). In addition the cluster consists of highly specialised niche firms within machine building, engineering and component suppliers. The Raufoss cluster includes a value chain from a foundry to automotive components in aluminium, including product development and tool production. The foundry and the extruding plant are owned by Hydro.

The Raufoss cluster was historically based on a large state-owned plant in the defence sector, Raufoss Ammunition factory (RA). The company was established in 1896 and grew into one of the largest companies in Norway with 2,100 employees and was totally dependent on military production until the 1950s (Onsager et al., 2007). The period as a state-owned company made long-term development of specialised knowledge possible, backed up by procurement by NATO and the Norwegian army. Since the 1950s RA entered civil production and aluminium profiles and automotive components became particularly important; first bumpers for Volvo in 1967, later other products to the global automotive industry. In order to meet the quality demands RA relied on R&D at Sintef. In 1994 the company exported 80 percent of its production, with the automotive industry as the main market. Hydro took over RA at the end of the 1990s and through this acquisition a value chain was integrated into Hydro and vital knowledge was exchanged between primary production and fabrication. A substantial restructuring was initiated, resulting in about 35 new firms, some of them with international owners (Onsager et al., 2007).

A considerable share of innovation activity in the Raufoss firms takes place as R&D projects. Sintef Raufoss Manufacturing (SRM), employing about 80 persons and majority owned by Sintef, functions as a local knowledge hub. The link to Sintef and the Hydro ownership demonstrates that the regional innovation system at Raufoss is embedded in a sectoral, national innovation system developing specific knowledge for aluminium production. For local firms SRM acts as a common R&D department in material science, automated and lean production methods (Author, 2011a). Competence at SRM is upgraded through demanding projects in cooperation with internationally competitive local firms and external research institutes. However, a 'pure' STI innovation mode is hardly found in the Raufoss case. This reflects amongst other things the learning organisation in many Norwegian firms. It is characterised by autonomy, learning and problem solving, and draws on employees' contribution to problem solving, which again demands experience-based knowledge from workers (Author, 2009).

The key companies, R&D institutes and government were pioneers in establishing a sectoral innovation system within aluminium in Norway. Aluminium production in Norway has been transformed from being based on natural resources and foreign technology in the 1960s to a mainly nationally owned and relatively knowledge-intensive industry. This has been vital for securing continued production in Norway when access to cheap energy has become a competitive advantage for producers located in such diverse places as Iceland, Qatar and Russia. The construction of a national innovation system has helped to secure national interests in the aluminium sector. On the doorstep of the petroleum era politicians could draw on vital experiences and institutions.

4. **Innovation systems to exploit North Sea oil and gas**

Norway is the second-largest exporter of gas and the fifth-largest exporter of oil globally. The petroleum companies operating on the Norwegian continental shelf employ 36,000 persons, while 85,000 are employed by specialised suppliers. More than half of this workforce is located in the south-western part of the country (Vatne, 2008). The sectoral innovation system within petroleum represents a major part of a national innovation system in which the national oil company Statoil is a key actor. Foreign petroleum companies, major suppliers, research institutes, universities, the Research Council and the Petroleum Directorate are other key actors within the national innovation system. A number of the leading suppliers are located in four–five regional clusters. The sector has a globally leading position in subsea field development where Norwegian petroleum companies together with suppliers have key positions in the development of fields offshore, e.g. in The Gulf of Mexico, Brazil and Angola.

According to a recent study, five phases of development and integration of a Norwegian petroleum innovation system can be identified (Engen, 2009, p. 186). It started with an *entrepreneurial phase* and continued with *early consolidation* in the 1970s when the innovation system was established. The pioneers started offshore oil production in the US (Schempf, 2007), but the discovery of the Groningen field outside Holland in the 1950s turned the interest among oil companies towards the Norwegian sector of the North Sea, which had corresponding geological structures. The environmental conditions in the North Sea represented a new frontier for the offshore oil companies and existing technologies were not adequate. No knowledge of oil exploration and production existed in Norway, and FDI was, as in the establishment of primary aluminium production some decades earlier, welcomed by the government. After the first discoveries of oil in the late 1960s, leading politicians wanted to establish a Norwegian oil industry, and a petroleum directorate and the company Statoil were established as part of this strategy. Statoil was founded 25 years after the aluminium company ÅSV – both publicly owned companies.

Another important means to secure national interests was the licensing system where oil companies had to apply for a concession to start drilling. Concessions were given on certain conditions, such as the establishment of onshore activities and the use of Norwegian suppliers. This was in principle the same method that was used early in the century when the aluminium industry was established. According to a historian: 'It is reasonable to assume that previous practice in the electricity concessions influenced the procedures for petroleum' (Engen, 2009, p. 181). Other historians have noted that the leading bureaucrats within the Department of Industry were well aware of how concessions had contributed to creating a national knowledge base within the aluminium sector and wanted to replicate this and establish a national oil industry in the 1970s (Ryggevik, 2009).

The harsh environmental conditions in the North Sea demanded new technological solutions to develop the oilfields and to meet environmental, health and safety standards. There were few ready-made solutions available and both international oil companies and suppliers had to extend their knowledge, and established offices in Norway and particularly in the Stavanger region. New solutions within offshore oil exploration were presented, many of them connected to the transportation of oil over long distances to the seabed. The introduction of 3-D computer technology in mapping possible oil and gas deposits is another important example of new technology developed for the North Sea petroleum activity (Vatne, 2008).

The situation within the Norwegian research sector was the same as within the industry: there was little or no prior knowledge about oil exploration and production. There were, however, knowledge of maritime operations within shipping and fisheries that were extended and converted as a response to a growing demand from the emerging oil industry. Existing knowledge in concrete construction was adjusted and utilised by the international oil companies from the early 1970s. At the Norwegian Institute of Technology and the University of Oslo research and education, respectively in petroleum engineering and in geology, were directed towards the challenges met by the offshore petroleum sector, and radically strengthened (Kobberød, 2007). At the University of Oslo's Geology Department research on the properties of sandstone as reservoir rock led to the upward adjustment of reserve estimates (Wright and Czelusta, 2003, p. 15). This represented the first move to establish a national science-based knowledgebase within oil exploration.

Signs of knowledge spillovers between the international oil industry and Norwegian suppliers already existed when the innovation system was in its infant stage. Goodwill agreements were, however, instrumental in establishing a national research capacity when the innovation system became more mature in its *third phase* during the 1980s. Foreign petroleum companies were given 'goodwill points' by contracting with Norwegian firms and research institutions and through the transfer of technology. Financial support to Norwegian R&D institutions together with transfer of know-how was especially valuable in the system for evaluating foreign firm's contributions to national absorptive capacity. The contribution of foreign firms to capacity building among Norwegian suppliers and research institutions was monitored and reflected in the next round of concessions. The taxation system was adjusted to support R&D, and 78 per cent of the costs were covered by the government (Engen, 2009, p. 193-194). A full-scale testing base for drilling activities was constructed at Rogaland

Research in Stavanger and it is still one of the most complete testing bases globally. Sintef initiated research within reservoir technology and multiphase seabed transportation of oil and gas during the 1980s. The contracts with multinationals exposed national actors to the international research frontier and one can argue that the construction of international seabed pipelines for transporting oil and gas led to the construction of knowledge pipelines. Statoil entered the role as a key actor in developing a national supplier industry and development contracts were established with Norwegian suppliers within mechanical engineering and former shipyards. This was the case even though there were more competent foreign suppliers (Nerheim, 1996).

In line with the increasing dominance by Norwegian companies in the domestic aluminium sector during the 1970s, the Norwegian oil industry strengthened its position considerably on the Norwegian continental shelf (NCS) during the 1980s. In both cases the shift was deliberately organized by the government. The sharp decline in oil prices in the late 1980s, however, led to action in order to restore profitability. Innovation was seen as a key in lowering the costs by 50 per cent, and a national programme with all the major actors was initiated in the *fourth phase* of the innovation system. Thus, during the early 1990s research efforts were central in bringing the costs on the NCS in line with the British sector. The Research Council had a major role in funding research, which soon resulted in technology for increased recovery rates. Research contributed to the reorganisation of field development from huge concrete design platforms to floating vessels in combination with seabed installations. Since the 1990s no major new fields have been discovered, but a number of smaller and less accessible fields that demand lighter and more flexible equipments have stimulated further research. Research and innovation were integrated in field development, and an STI mode of innovation emerged as an integral part of the petroleum sector, together with the until then dominant DUI mode of innovation. The fourth phase of the innovation system marks a more fully fledged co-evolution between the petroleum industry, authorities and research institutions. Twenty years after the entrepreneurial phase both industry, authorities and research institutions had acquired relevant research capabilities and started systematic co-operation across institutional borders.

The sectoral innovation system within petroleum has managed both to develop cost-effective technologies for the exploitation of petroleum under harsh environmental conditions and to become globally competitive in a number of niches (Engen, 2009, p. 203). During the current *fifth phase* of the innovation system networks within the Labor Party and the Norwegian Confederation of Trade Unions and industry have promoted national R&D programs on petroleum. A significant natural-gas-based R&D program was launched in 2007 because political networks, including trade unions and regional interests, were mobilized (Kasa and Underthun, 2010). The recent development of new deep-water fields are typically organised in projects with key actors located in Houston and Stavanger and research facilities at Sintef and at Rogaland Research. A symbiotic relationship exists between oil companies and their suppliers, where innovations based on a user-producer relationship established on the NCS have been instrumental in the globalisation of both the petroleum industry and the suppliers. The globalisation of the operations of Statoil, however, has not been very successful. After 20 years Statoil is not yet an independent operator of fields abroad and it still ranks among the smaller companies internationally (Ryggevik, 2009). Some Norwegian suppliers have been more successful than the national oil company in their global expansion.

It is important to notice that a number of these globally competitive firms are located in regional clusters. Of the 12 regional clusters appointed by Innovation Norway as Norwegian

Centres of Excellence, 5–6 have the petroleum industry as their main market. The subsea cluster outside Bergen is one of the most complete subsea petroleum clusters globally, and the supplier industry in the Agder region in south Norway is also totally dependent on the demand from the petroleum industry. Other regional clusters with a strong position in the petroleum industry are the systems engineering cluster in Kongsberg, the instrumentation industry in Trondheim and the maritime cluster in western Norway. These are regional clusters working within regional, national and international innovation systems.

The oil and gas supplier industry at Agder

The oil and gas equipment suppliers at Agder are one regional cluster dependent on deliveries to the petroleum industry and illustrate the public efforts to build a national petroleum industry. The Agder firms benefited from the favouring of national suppliers for deliveries to the NCS and the technology transfer initiatives. However, local entrepreneurs managed to utilise the window of opportunity found in deliveries by Norwegian firms, and local start-ups represent much of the origin of the Agder supplier cluster. This point to the fact that national policy is an important, but not sufficient condition for the establishment and growth of supplier firms.

The Agder cluster consists of about 45 firms and 6,000 jobs including a variety of firms concerning products, size, ownership and innovation modes (Author, 2011b). Agder firms are world leading within drilling equipment, loading and anchoring equipment and cranes with active compensation systems. The firms are locally embedded through a local production system, a specialised labour market and formal and informal collaboration between firms (Author, 2009). Local embedding seems to characterise the situation even if nearly half of the firms, and in particular the largest and most advanced ones, have been acquired by multinationals.

The cluster has traditionally been dominated by the DUI innovation mode. Firms have mainly learned by fulfilling requirements from demanding customers among petroleum companies, rig operators and shipping companies. Thus, the innovation activity has mainly taken place within customer projects as frequent, incremental improvements in products. Firm's rate information and ideas that build on experiences developed through the daily work and inquiries from customers as by far the most important sources of information, while information from knowledge organisations is less important (Author, 2011b). These results underline the fact that the equipment supplier industry at Agder has grown in close collaboration with customers and through the building of specialised, and to some extent tacit, knowledge within the firms.

This mainly DUI innovation mode is currently being modified and some firms establish R&D departments and organise the innovation activity through R&D projects. Firms no longer introduce incremental improvements in nearly every project, but standardise products and have a more strategic view of the timing of component and product revisions. The organisation of internal R&D projects also facilitates collaboration with external knowledge organisations. Thus, firms have increased their cooperation with both regional and national universities and R&D institutes during the last years. The still-dominant customer-driven innovation activity is thus supplemented by more strategic R&D activities and more use of the national innovation system.

5. Discussion and conclusion

The primary research question of the paper is which mechanisms have been decisive in creating innovation systems within the aluminium and petroleum sectors in Norway? The paper demonstrates that the two sectors are embedded in national innovation systems consisting of major companies, their supplier and downstream industries, R&D institutes, universities and not least policy measures. The innovation systems did not emerge as manna from heaven, nor as a result of a master plan consciously implemented through decades of deliberate action. Instead we have a case of specialisation patterns that have been relatively unique and stable over time and which resulted in innovation systems with a certain amount of autonomy (Lundvall et al., 2002, p. 218). The innovation systems have evolved partly as a self-organised process between industry and knowledge organisations. Still, this development would have been impossible without active state policy. Both the aluminium and petroleum sectoral innovation systems have relied on old public institutions, such as the concession acts. Politicians and key actors in the petroleum sector have reflected upon the history of aluminium when formulating their strategies, something which the overlapping political–industrial networks of the sectors indicate.

The second research question concerns the theoretical lessons that can be drawn from our study of the two natural resource industries in Norway. We will point out four main lessons. Firstly, the paper has demonstrated the relevance of analysing the historical development of innovation systems to understanding the creation of their specific path-dependent characteristics and not just studies of the current set-up and working of the system. Narula (2002) argues that Norwegian resource-based firms in general are 'locked-in' to the systems of innovation, which restrict their activities. Narula's study was a snapshot of some industries at the turn of the century and did not include the petroleum sector, which makes it understandable why his conclusions appear somewhat pessimistic. Our historical approach demonstrates that natural resource industries at a mature stage today are based on former radical technical and organisational innovations, i.e. that the industries at certain stages in their life cycles have been highly innovative and dynamic. What is particular for these industries in a Norwegian context is that foreign capital was attracted by the natural resources which subsequently were subject for national control through the Concession Act. This put the state in a position to negotiate terms of investments, production and R&D. The implications have been increased dominance of national capital and knowledge spill-over as a starting point for a deliberate evolution of a national innovation system. The analysis reveals prevailing radical innovations in some parts of the natural resource industries, such as within subsea offshore oil and gas production. The innovation pressure within natural resource industries also results in a search for substitutes, such as alternative energy sources. Thus, the Norwegian solar cell industry has become a global player by employing already familiar know-how, scientific knowledge and technology, mainly from the process industry in new fields (Hanson, 2008). The solar cell industry uses the same national R&D institutes that have been important for the development of the aluminium sector, and new factories are located at the same places as existing aluminium and other process industry plants (Author, 2008). By this location the new plants benefit from the existing physical infrastructure and the knowledge and experience of workers at these places. The historical analysis also demonstrates that the national systems are, and have been, open through external ownership and increasingly through links to foreign R&D institutes. The aluminium, petroleum and emerging solar cell industries are important actors within national innovation systems, but they are also firmly embedded in international networks that diffuse knowledge and hinder lock-ins.

A second lesson from the analysis of the two natural resource sectors concerns the vital role of political decisions and policy tools in stimulating new national industries and innovation systems. The industrial policy has traditionally focused on state ownership, technology transfer by foreign multinational enterprises; 'and preferential treatment for Norwegian firms, firms with Norwegian partners, or firms that had transferred significant components of their technological activities to Norwegian locations' (Narula, 2002, p. 802–803). The Norwegian cases emphasise the importance of investigating how policy can influence the development and working of innovations systems. This is also our contribution to the debate over the fate of resource based economies. The mechanisms that resulted in linkages between the aluminium and petroleum sectors and the wider industrial and territorial development of the economy have supported innovation activity. Innovative solutions have made possible job growth in the petroleum and aluminium sectors that so far have offset some of the crowding out of traditional export industries. This situation might however not last forever and Norway, with shrinking oil production, could be a future case of Dutch disease.

Although the development of the Norwegian natural resource industries stresses the importance of the national level, it also demonstrates the need for a multilevel approach, which is our third main lesson. The multilevel organisation of innovation activity is illustrated, in particular, by the regional cluster of automotive component producers at Raufoss and the oil and gas equipment suppliers at Agder. Firms in both clusters have benefited from national industrial policies favouring Norwegian suppliers on the NCS, and they source knowledge from the largest national universities and R&D-institutes. The lead firms in both clusters are, however, integrated in global value chains and knowledge networks, they supply a global market and are often parts of foreign multinational enterprises. The firms simultaneously benefit from being located in knowledge-intensive regional clusters with a specialised local labour market. Thus, studies of innovation systems should consider the fact that firms and industries generally are parts of different types of innovation systems.

The development of the two regional clusters points to the last main lesson. Our analyses demonstrate close links between the two natural resource-based industries and their upstream and downstream industries. In this context, the two autonomous groups of Norwegian firms in Narula (2002) may be somewhat misleading. Narula distinguishes between the traditional resource-based industries and formerly protected firms on the one hand, and specialised and technology-intensive companies on the other hand. Our analyses point to the fact that the last group of companies partly supplies the former group of customer companies, for example with control and measuring equipments, or partly emerges as sophisticated downstream activities, stimulating upstream development as well. Our last lesson is thus that innovation processes in different industries are often linked in value chains and through knowledge flow, which is also a core lesson from the innovation system approach.

References

Asheim, B.T., 2007. Differentiated knowledge bases and varieties of regional innovation systems. Innovation 20 (3), 223–241.

Cappelen, Å., Mjøset, L., 2009. Can Norway Be a Role Model for Natural Resource Abundant Countries? United Nations University-Wider Research Paper no. 23.

Cooke, P., 2004. Complexity and industrial clusters: Dynamics and models in theory and practice. European Planning Studies 12 (4), 595-9.

Cooke, P., Boekholt, P., Tödtling, F., 2000. The Governance of Innovation in Europe. Regional Perspectives on Global Competitiveness. Pinter, London.

Edquist, C., 2005. Systems of innovation. Perspectives and challenges. In; Fagerberg, J., Mowery, D.C., Nelson, R.R. 2005 (Eds.), The Oxford Handbook of Innovation. Oxford University Press, Oxford, pp. 181–208.

Engen, O.A., 2009. The development of the Norwegian Petroleum Innovation System: A historical overview. In: Fagerberg, J., Mowery, D., Verspagen, B. (Eds.), Innovation, Path Dependency, and Policy. Oxford University Press, Oxford, pp. 179–207.

Fagerberg, J., Mowery, D.C., Verspagen, B., 2009. Introduction: Innovation in Norway. In: Fagerberg, J., Mowery, D., Verspagen, B. (Eds.), Innovation, Path Dependency, and Policy. Oxford University Press, Oxford, pp. 1–29.

Fagerberg, J., Mowery, D.C., Nelson, R.R., (Eds.), 2005. The Oxford Handbook of Innovation. Oxford University Press, Oxford.

Freeman, C., Louca, F., 2001. As Time Goes By. From the Industrial Revolutions to the Information Revolution. Oxford University Press, Oxford.

Gregersen, B., Johnson, B., 1997. Learning economies, innovation systems and European integration. Regional Studies 31 (5), 479–490.

Grønning, T., Moen, S.E., Olsen, D.S., 2008. Low innovation intensity, high growth and specialised trajectories: Norway. In Edquist, C., Hommen, L. (Eds.), Small Country Innovation Systems. Globalisation, Change and Policy in Asia and Europe. Edward Elgar, Cheltenham, pp. 281–318.

Hanson, J., 2008. Fra silisium til solceller – fremveksten av norsk solcelleindustri. In: Hanson, J., Wicken, O. (Eds.), Rik på natur.. Innovasjon i en ressursbasert kunnskapsøkonomi. Fagbokforlaget, Bergen, pp. 43–58.

Hirschman, A. (1977) The Passions and the Interests: Political Arguments for Capitalism before its Triumph. Princeton University Press, New Jersey.

Jensen, M.B., Johnson, B., Lorenz, E., Lundvall, B.Å., 2007. Forms of knowledge and modes of innovation. Research Policy 36 (5), 680–693.

Kasa, S., Underthun, A., 2010. Navigation in new terrain with familiar maps: Masterminding socio-spatial equality through resource oriented innovation policy. Environment and Planning A, 42, 1328-1345.

Kobberød, J.T., 2007. Visjonen om det integrerte petroleumsmiljøet. In: Børresen, A.K., Kobberød, J.T. (Eds.), Bergingeniørutdanning i Norge gjennom 250 år. Tapir Akademisk Forlag, Trondheim.

Lambooy, J.G., 2004. The transmission of knowledge, emerging networks, and the role of universities: An evolutionary approach. European Planning Studies 12 (5), 643–657.

Lundvall, B.-Å., 2007. National innovation systems – Analytical concept and development tool. Industry & Innovation 14 (1), 95–119.

Lundvall, B.Å., Johnsen, B., Andersen, E.S., Dalum, B., 2002. National systems of production, innovation and competence building. Research Policy 31 (2), 213–231.

Malerba, F., 2004. Sectoral systems: Concepts and issues. In: Malerba, F. (Ed.), Sectoral Systems of Innovation. Cambridge University Press, Cambridge.

Martin, R., Sunley, P., 2010. The place of path dependence in an evolutionary perspective on the economic landscape. In Boschma, R. and Martin, R. (eds.), The handbook of Evolutionary Economic Geography. Edward Elgar, Cheltenham (62-92).

Mehlum, H., Moene, K., Torvik, R., 2006. Cursed by resources or institutions? The World Economy 29 (8), 1117–1131.

Midtun, A., 2007, The Negotiated Political Economy of a Heavy Industrial Sector: The Norwegian Hydropower Complex in the 1970s and 1980s. Scandinavian Political Studies 11(2), 115-144.

Moen, S.E., 2009. Innovation and production in the Norwegian aluminium industry. In: Fagerberg, J., Mowery, D., Verspagen, B. (Eds.), Innovation, Path Dependency, and Policy. Oxford University Press, Oxford, pp. 149–179.

Murmann, J.P., 2003. Knowledge and Competitive Advantages: The Coevolution of Firms, Technology, and National Institutions. Cambridge University Press, Cambridge.

Narula, R., 2002. Innovation systems and ‘inertia’ in R&D location: Norwegian firms and the role of systemic lock-in. Research Policy 31 (5), 795–816.

Nelson, R.R., 1993. A retrospective. In: Nelson, R.R. (Ed.), National Innovation Systems. A Comparative Analysis. Oxford University Press, Oxford, pp. 505–523.

Nelson, R.R., 1995. Co-evolution of industry structure, technology and supporting institutions, and the making of comparative advantage. International Journal of the Economics of Business 2 (2), 171–184.

Nelson, R.R., 2002. Bringing institution into evolutionary growth theory. Journal of Evolutionary Economics 12, 17–28.

Nerheim, G., 1996. Norsk oljehistorie. En gassnasjon blir til. Norsk Petroleumsforening, Oslo.

Onsager, K., Isaksen, A., Fraas, M., Johnstad, T., 2007. Technology cities in Norway: Innovating in global networks. European Planning Studies 15 (4), 549–566.

Perman, R., Ma, Y., McGilvray, J., Common, M. 2003. Natural Resource and Environmental Economics. Pearson Education Limited, Essex.

Rees, J., 1990. Natural resource: allocation, economics and policy. Routhledge, London.

Ryggevik, H., 2009. Til siste dråpe. Om oljens politiske økonomi. Aschehoug, Oslo.

Sachs, J.D., Warner, A.M., 2001. The Curse of Natural Resources. European Economic Review 45 (4-6), 827-38.

Sachs, J.D., Warner, A.M., 1997. Natural resource abundance and economic growth. Centre for International Development and Harvard Institute for International Development, Cambridge MA.

Sandvik, P.T., 2008. European, global or Norwegian? The Norwegian aluminum companies, 1946–2005. In: Schröter, G.H. (Ed.), The European Enterprise. Historical Investigation into a Future Species. Springer, Berlin, pp. 241–252.

Schempf, F.J., 2007. Pioneering Offshore: The Early Years. Pennwell Books, Houston.

Simpson, R.D., 1999. Introduction: Technological innovation in natural resource industries. In: Simpson, D.R. (Ed.), Productivity in Natural Resource Industries. Improvement through Innovation. Resources for the Future, Washington DC, pp. 1-34.

Smith, K., 2008. Innovasjon og vekst i ressursbaserte økonomier. In: Hanson, J., Wicken, O. (Eds.), Rik på natur. Innovasjon i en ressursbasert kunnskapsøkonomi. Fagbokforlaget, Bergen, pp. 11–24.

Von Tunzelmann, N., Acha, V., 2005. Innovation in 'low-tech' industries. In: Fagerberg, J., Mowery, D.C., Nelson, R.R., (Eds.), The Oxford Handbook of Innovation. Oxford University Press, Oxford, pp. 407–432.

Vatne, E., 2008. Olje og gass – en ny næring i hurtig vekst. In: Isaksen, A., Karlsen, A., Sæther, B. (Eds), Innovasjoner i norske næringer – et geografisk perspektiv. Fagbokforlaget, Bergen, pp. 101-120.

Wicken, O., 2008. Manna fra himmelen eller kunnskapsbaserte produkter? In: Hanson, J., Wicken, O. (Eds.), Rik på natur. Innovasjon i en ressursbasert kunnskapsøkonomi. Fagbokforlaget, Bergen, pp. 25–42.

Wolfe, D.A., 2005. Innovation and research funding: The role of government support. In: Iacobucci F., Carolyn, J.T. (Eds.), Taking Public Universities Seriously. University of Toronto Press Incorporated, Toronto, pp. 340–341.

Wright, G., Czelusta, J., 2003. Mineral Resources and Economic Development. Paper presented at the Conference on Sector Reform in Latin America, Stanford Centre for International Development, November 13-15.

Caption for Figure 1

Figure 1. GNP pro capita and export values for aluminium and petroleum for Norway 1950-2009. Source: Statistics Norway.