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This paper analyses the co-evolution of science, technology and innovation policy and industrial structure in a small, open, resource-based economy (Norway). The contributions of the paper are threefold. First, it develops an evolutionary and historically oriented approach to the study of the development of these policies that may have wide applicability. Second, it focuses on a particular type of innovation, innovation in resource-based activities, that differs in many respects from the more commonly studied case of innovation in 'high-tech' industries. Third, the paper advances our understanding of the roles played by institutions and politics in innovation. Previous work on national systems of innovation has devoted little attention to these matters, possibly because much of this work examines 'snapshots' of various innovation systems at a specific point in time and lacks historical depth.

THE 'NATIONAL INNOVATION SYSTEM' concept first appeared in work by Christopher Freeman (1987), Bengt Åke Lundvall (1992) and Richard Nelson (1993), and this analytic framework has since been extensively discussed in both scholarly and policy-analytic work (Sharif, 2006). Yet despite the popularity of the concept, scholars disagree on how best to apply the innovation system concept to individual nations (Edquist, 2004). This paper argues that the development of national innovation systems is best studied as a historical process.[1] The emergence and evolution of an innovation system rests on a co-evolutionary process, in which the development of firms and industries, on the one hand, interacts with and affects a national public research infrastructure, policies and institutions, on the other. Such co-evolutionary processes may also give rise to path dependencies of various sorts, for example, processes that systematically favor some types of activities (or solutions or ideas) while constraining others (Arthur, 1994; Narula, 2002). Path dependencies extend beyond economic structures and interactions to include institutions and policies (North, 1990; Pierson, 2000).

The national innovation systems concept has been used in both a narrow and a broader sense (Edquist, 2004). The narrower definition of the national innovation system includes innovative firms and the public research infrastructure with which they interact in varying degrees (Nelson, 1993). The broader definition extends to include all learning and innovation activities in a country regardless of where these take place (Lundvall, 1992, 2003; Edquist, 2004). This paper uses a broad definition of the concept.[2] Thus we consider more than the organizations (e.g. universities and research institutes) that develop and transmit knowledge, or organizational units within firms, such as R&D departments, that seek to develop and exploit knowledge.

This broader perspective is essential for several reasons. First, innovation and knowledge yield economic benefits less from their creation than from their application to the production of new and existing goods and services. An exclusive focus on the creation of new technologies that ignores their exploitation risks overlooking essential cross-national differences in the translation of new knowledge into economic gains. The effective exploitation of new

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knowledge or technology is especially important for small countries such as Norway, whose contribution to the global pool of knowledge necessarily is dwarfed by the potential contributions from effective exploitation of this pool for Norway's economic growth. Second, in Norway as well as elsewhere, considerable learning and innovation occur outside of the boundaries of organizations created specifically to support innovation (Lundvall, 1992, 2003, 2007). Ignoring the contributions to economic prosperity from these 'non-formal' innovation-related activities may yield a biased account of the sources of economic growth that in turn yields misleading policy guidance. Third, since sectors and industries differ in the ways in which learning and innovation occur within their boundaries (Pavitt, 1984; Malerba, 2004), the use of a broad perspective for understanding innovation is especially important in examining a nation such as Norway, since its pattern of economic specialization differs significantly from that of most other high-income economies.

This paper employs historical and evolutionary perspectives to analyze the development of the Norwegian innovation system. In the next section we outline the paper's theoretical perspective in more detail and relate it to other literature on the subject. The third section presents an analysis of the contemporary Norwegian innovation system and compares it with other countries on a similar level of economic development. This analysis highlights some important differences between the Norwegian innovation system and those of its Nordic neighbors, Finland and Sweden. One unusual feature of the Norwegian innovation system that has been characterized as 'paradoxical' (OECD, 2007; Grønning *et al*, 2008) is the fact that Norway combines high growth in productivity and income with comparatively low levels of investment in R&D. Although paradoxical by comparison with other industrial economies, these features of Norway's economy and innovation system reflect the historical development of the Norwegian economy, as we point out in the fourth section. The final section summarizes the lessons of our study.

Innovation, path dependency and policy: theoretical perspectives

Evolutionary approaches to the analysis of innovation emphasize variety creation, adaptation, selection and retention, all of which are time- and path-dependent. At any point in time many new ideas emerge, but only those that are well adapted to the contemporary selection environment are likely to be applied and form the basis for continuing adaptation and improvement. This selection process is associated with a Schumpeterian process of technological competition (Fagerberg, 2003), characterized by entry (and exit) of firms, continuous innovation, gradual development of standards, the adaptation or creation of institutions, etc.

Nevertheless, there are important differences among industries or technological fields in the operation of these processes (Pavitt, 1984; Carlsson and Stankiewicz, 1991; Malerba, 2004). For example, in pharmaceuticals or biotechnology, codified knowledge, university research and formal instruments for protection of intellectual property (e.g. patents) are very important, while in some other fields, such as the auto industry, ship-building and construction, these factors are less important than in-house learning, interaction with customers and suppliers, or secrecy (Malerba, 2004; Von Tunzelmann and Acha, 2004).

A national system of innovation consists of firms in many different sectors operating within a common (national) 'knowledge infrastructure' and a common institutional and political framework. The sectoral composition of a given national economy therefore influences the operation and structure of its national innovation system, even as the national innovation system affects the performance of its constituent sectoral systems. Hence, the relationship between sectoral and national innovation systems is a co-evolutionary one, in which sectoral characteristics (and the needs of firms in these sectors) influence the development of the knowledge infrastructure, institutions and policies at the national level, while these factors influence the subsequent evolution of the national economy, including its sectoral composition.

The importance and extent of path dependency within innovation processes have given rise to a large literature (Arthur, 1989, 1994; David, 1986; North, 1990; Grabher, 1993; Liebowitz and Margolis, 1994, 1995; Pierson, 2000; Niosi, 2002; Martin and Sunley, 2006). Within economics, much of this literature has focused on mechanisms that may lead to economies of scale, such as the adoption of standards. However, institutions and politics may also be relevant in this context (Pierson, 2000; Whitley, 2002). Institutions or 'rules of the game' (North, 1990) are difficult and costly to establish but facilitate economic interactions enormously once adopted, leading to scale advantages. Thus, institutions and, arguably, politics (Rose, 1990) may be important sources of path dependency in their own right (North, 1990).

The national innovation system is also the selection environment for new entrepreneurial ventures, and path dependency influences these selection processes. New ventures that have little in common with economically strong existing sectors may find that the national innovation system is poorly adapted to their needs. Narula (2002), for example, argued that the development of Norway's innovation system has produced a structure of policies and institutions that provide little support for new, knowledge-intensive sectors.

Although path dependency has been important in the evolution of the Norwegian and other national innovation systems, the development of these systems is affected by more than past developments alone. Innovation systems are open systems; new initiatives do appear within them, and the selection processes that winnow out these initiatives are complex and operate at multiple levels.[3] It is unrealistic to portray the knowledge infrastructure, entrepreneurs, and political coalitions within even a relatively small nation such as Norway as monolithic. For example, as we will show below, Norwegian entrepreneurs with contrasting interests and economic visions exploited different political groups with conflicting perceptions of the economic future to gain political and financial support for new undertakings.

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The Norwegian innovation system in comparative perspective

Norway was once one of the poorer countries in Europe. According to Maddison (2003), in 1870 Norway's gross domestic product (GDP) *per capita* was only three-quarters of the Western European average. By 1973, however, Norway had caught up with most Western European countries and, by 2001, Norway's GDP *per capita* was one quarter higher than the Western European average. Hence by the beginning of the 21st century, Norway had become one of the richest countries in the world.

How can such a remarkable episode of economic growth be explained? The explanation of international differences in economic performance has been a central theme for economists since Adam Smith first raised the question in his study of *The Wealth of Nations* (1776). Until recently, however, most economists' thinking about the subject focused on such factors as natural-resource endowments, labor supply and capital accumulation. More recent research, however, has shifted its focus towards intangibles such as knowledge or innovation.[4]

Innovation is often associated with high-technology industries, such as information and communication technologies, scientific research in large-scale facilities in firms or universities, and professionals working in urban environments. Norway, however, has no major international firms in high-tech industries, and no university that ranks among the top 50 worldwide. Moreover, Norway's population is small (currently 4.6 million) and the country is among the 50 countries with the lowest population density in the world (about 12 people per km^2). Its capital and largest city, Oslo, has just over half a million inhabitants. These characteristics are rarely associated with strong national innovative performance, especially in knowledge-intensive industries.

Figure 1 compares Norwegian GDP *per capita* (measured in purchasing power parity terms) with regional GDP *per capita* in Western Europe.[5] The thin black line shows the Norwegian level, and the thick black line indicates the Western European average. As we noted earlier, postwar Norwegian GDP *per capita* was roughly equal to the Western European average until the first oil crisis of the 1970s, which led to recession and lower growth elsewhere in Europe. Norway was less seriously affected by the recession, and experienced more rapid growth than the other countries in Western Europe after the mid-1970s. This Norwegian 'growth spurt' is related to the discovery of Norway's offshore oil and gas fields that began production in the early 1970s (the two dotted lines in Figure 1 depict Norwegian oil and gas production). Although oil and gas production remained low in the first half of the 1970s, output subsequently grew rapidly, and this sector's importance within the Norwegian economy increased dramatically from 1975 onwards.

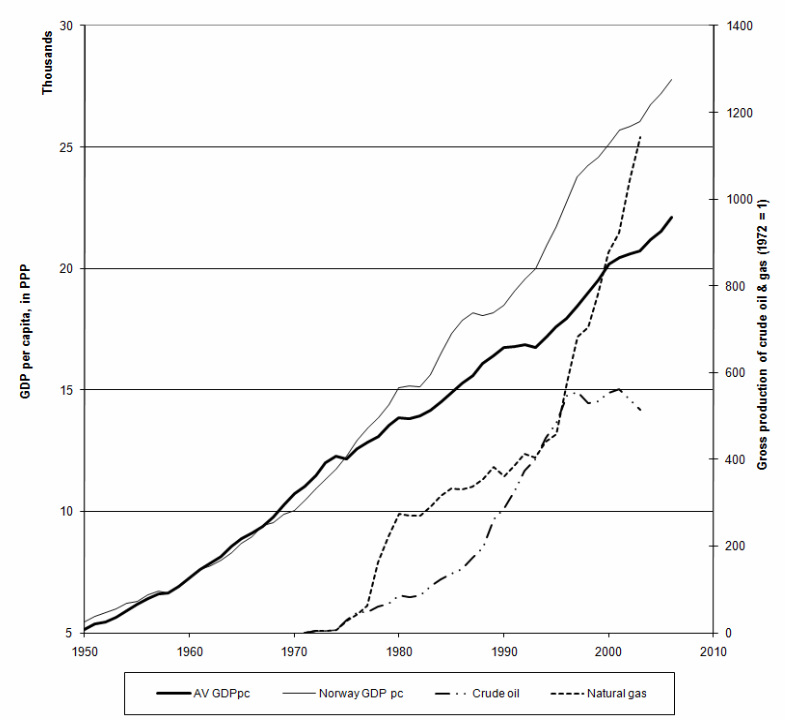

Figure 1. Norwegian economic growth and the rise of the oil and gas sector, 1950–2007
Source: GGDC Total Economy Data Base www.ggdc.net for GDP pc data, Statistics Norway for oil and gas data

Norway was not the only northwest European nation to discover and exploit offshore oil and gas deposits during the 1960s and 1970s — the United Kingdom, Denmark, and the Netherlands all benefited from similar discoveries. Nonetheless, the transformative effects of oil and gas appear to have been most significant in the Norwegian economy. Although Norway's oil and gas sector accounts for a small share of national employment, the sector's development opened up a huge market that Norwegian manufacturing and services firms successfully exploited, partly as a result of public policy. Firms in sectors such as shipbuilding, engineering, ICT and other business services expanded their sales in this rapidly expanding market, aided by supportive governmental policies (see Engen, 2009). In the Netherlands, another small open economy, oil and gas production was associated with de-industrialization, the so-called 'Dutch disease', resulting from the appreciation of its currency a loss in competitiveness within domestic manufacturing. In Norway, however, the growth of the oil and gas sector benefited domestic manufacturing industry, output from which arguably grew more rapidly than otherwise might have been the case (Cappelen *et al*, 2000).

The rapidly increasing income from the oil and gas sector also enabled Norway's government to pursue a more expansionary fiscal and monetary policy than those of other Western European governments during the 1980s and 1990s. Consequently, Norwegian rates of labor force participation and economic growth were consistently higher — and unemployment markedly lower — than in Western Europe as a whole. Norwegian GDP *per capita* now is approximately one quarter higher than the Western European average (Figure 1). About one half of this difference can be explained as rents from oil and gas production (reflecting returns to investment in physical capital above what is 'normal' in the economy as a whole).[6] It should be emphasized, however, that by allowing high growth in demand, high labor force participation and rapid (and economically beneficial) structural changes, the oil and gas sector also had important indirect effects on the economy. What Norwegian GDP *per capita* would have been in the absence of oil and gas exploration is a difficult question that we cannot pursue in the necessary detail here.[7] But it seems likely that Norway's economic development without oil and gas would not differ dramatically from that of its neighbors, Denmark and Sweden.

Although oil and gas now is Norway's most economically important resource-related industry, Norwegian economic development historically has relied on the exploitation of a rich natural resource endowment. Most of these resources were related to the geography of the country, such the sea (fishing, shipping and related industries), and other opportunities created by Norway's mountainous terrain for mining and production of hydroelectric power, which provided the basis for the nation's electrometallurgical and -chemical industries. Although these sectors now account for a smaller share of Norwegian GDP than in previous periods, they are important sources of income and employment in some regions of Norway and retain considerable influence in Norwegian domestic politics. They also contribute significantly to Norway's exports.

Figure 2 illustrates the Norwegian pattern of specialization in production of tradable goods and services in 2002, relative to the European average. The index has a zero mean and varies between unity (indicating products that are produced only in Norway) and minus one (not produced in Norway).[8] It shows that in addition to its large oil and gas sector, Norway remains highly specialized in fisheries, shipping and related industries. During the second half of the 20th century, Norway pioneered the development of fish-farming, and the nation remains among the global leaders in this industry. As we noted earlier, the shipbuilding industry has retained its economic significance within Norway by diversifying into production of equipment for exploration and production of oil and gas. The basic metals sector, a large user of hydroelectric power, is another natural resource-based sector in which Norway remains specialized.

The relationship between Norway's pattern of economic specialization and its innovation system is a central theme of this paper and the topic of long-running policy debates in Norway. As was noted above, one view of the role of technology in economic growth holds that a strong high-technology industrial base (consisting of ICT, biotech, new materials, pharmaceuticals, and selected other industries) is necessary for prosperity. As we argue in the following section, however, Norway's resource-based sectors (aluminium, oil and gas, and fish-farming) have for decades been highly innovative, drawing on domestic sources of innovation, technology transfer from foreign sources (the success of which relied on substantial indigenous Norwegian 'absorptive capacity') and Norway's universities and research institutes.

One manifestation of the strong performance of Norway's economy during the past 30 years is its high rate of labor productivity growth, which has averaged more than 2.5% per year since 1975 (OECD, 2007). This strong economic performance, however, is associated with much lower levels of R&D investment than in most other high-income European economies.[9] Figure 3 compares R&D spending as a share of GDP in Norway with that of other high-income industrial economies, and shows that Norway's R&D/GDP ratio of 1.6% is in the lower half of the reference group. Moreover, like most other countries with low R&D intensity, Norway's economy is characterized by a relatively large share of government-financed R&D, which consists mainly of R&D carried out in universities and institutes within the public sector.

Although R&D spending is widely used in cross-national comparisons, it is only one of several important factors contributing to strong national innovative performance. In fact, the importance of R&D investment relative to other factors varies substantially among economic sectors (Fagerberg *et al*, 2004). Does the unusual Norwegian pattern of specialization by comparison with other European economies explain its lower levels of R&D investment? For instance, it is possible that the sectoral innovation systems in Norway's fields of specialization operate differently, or rely on sources of innovation that require lower levels of R&D investment, than in other European economies. We examine this question by controlling for cross-national differences in economic specialization patterns when comparing R&D investment levels across countries.

For example, the ICT industry is very R&D-intensive, and accounts for a large share of Swedish GDP. Norway's ICT industry, however, is small. This structural difference between the two economies contributes to the higher GDP share of R&D

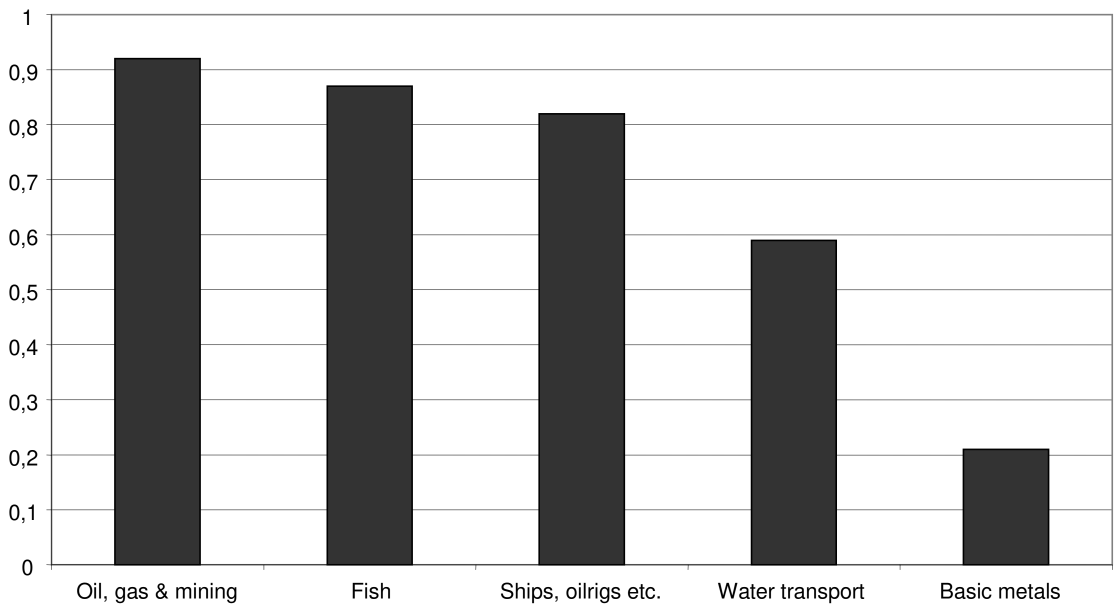

Figure 2. The five leading areas of Norwegian specialization, based on production of tradable goods and services in 2002
Source: GGDC 60 Industries Data Base <www.ggdc.net>

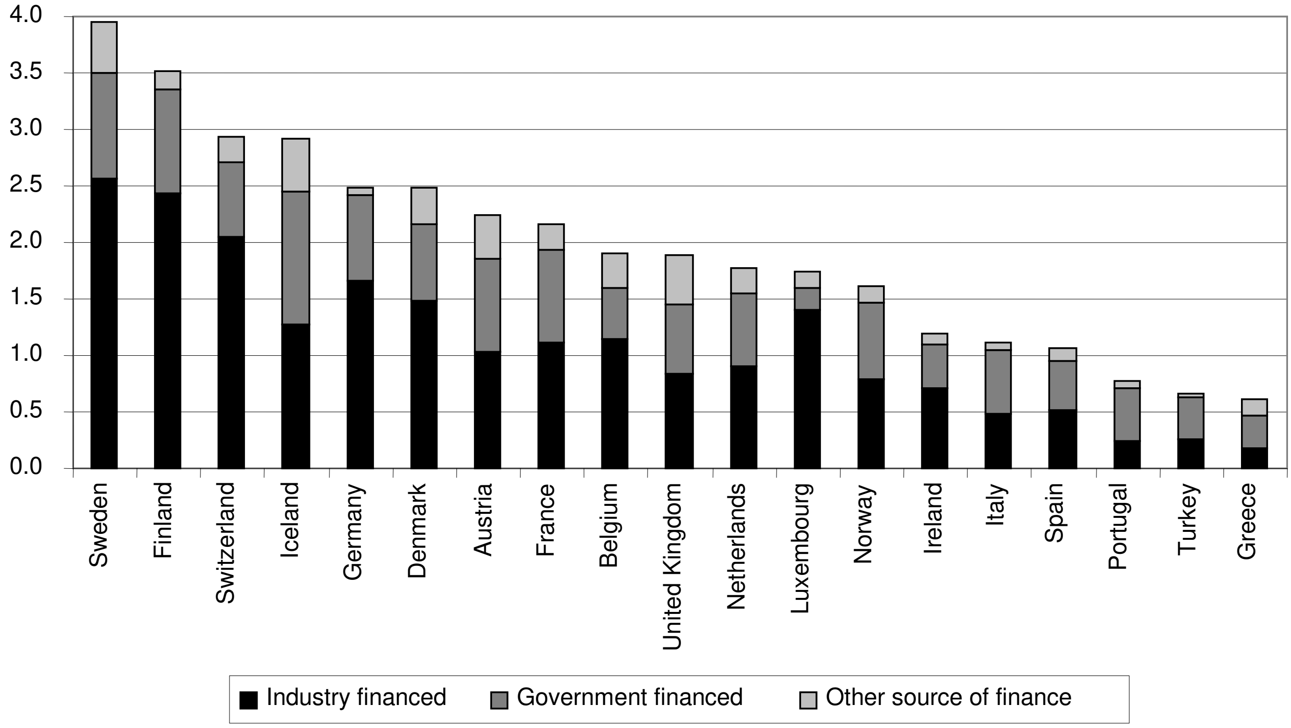

Figure 3. R&D as a percentage of GDP: Norway and a reference group of European economies, 2004
Source: OECD

performed in industry in Sweden relative to Norway. By using a common set of sectoral weights when comparing Norway and Sweden, we are able to control for the effects of such structural differences.[10] Figure 4 compares the share of value added accounted for by Norwegian business R&D (R&D performed within industry) with similar figures for other Western European countries as reported by the OECD ('actual') and weighted by the industrial structure of the country with which Norway is compared ('adjusted'). If Norwegian firms on average do more R&D than firms in the same sectors in the other country, the 'adjusted' ratio will be above one and vice versa.

The results reported in Figure 4 indicate that Norway's economic structure affects its low R&D/GDP ratio. In five out of the six comparisons (the exception being Sweden, a nation with one of the highest R&D/GDP ratios in the world), Norwegian firms perform as much business-enterprise R&D as

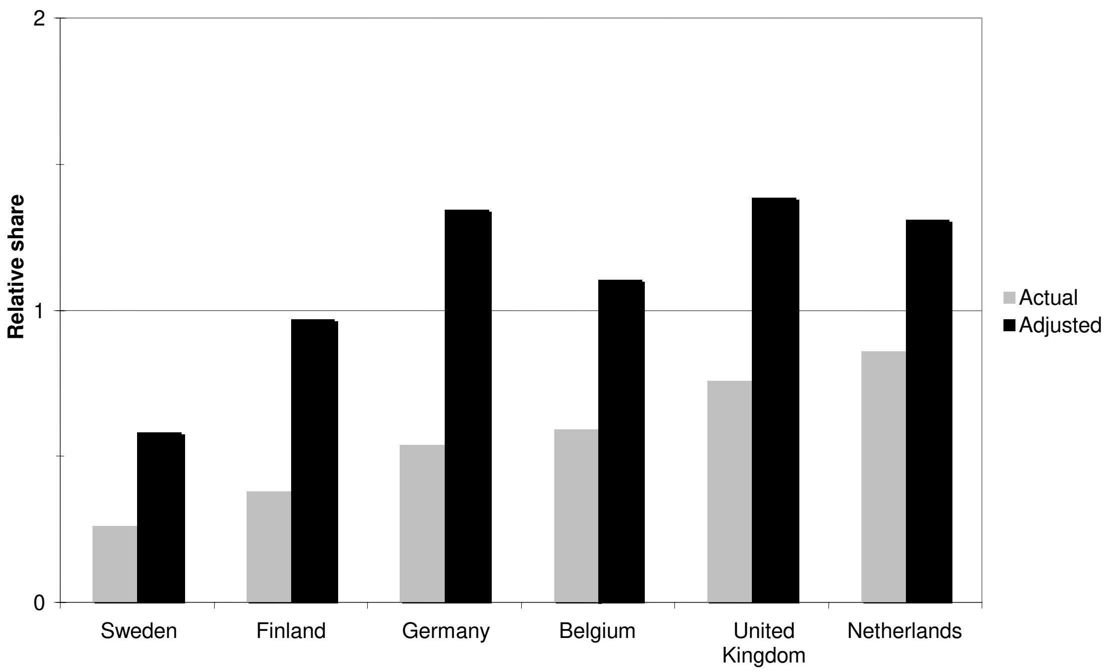

Figure 4. Norway's share of business R&D in GDP relative to those of other countries, actual and adjusted for structural differences, 2001/2002
Source: Authors' calculations based on OECD and Eurostat data

do foreign firms in the same sectors. The finding that the low level of Norwegian R&D is influenced by the nation's pattern of economic specialization is corroborated by the results of other studies (OECD, 2007). Nonetheless, as we pointed out earlier, R&D is only one factor in innovation, and R&D investment data may not capture other important aspects of sectoral or national innovation-related activity. One source of data that covers a broader set of innovation-related activities is the Community Innovation Survey (CIS), carried out throughout Europe. Innovation in this survey is a broad concept that includes the introduction of production and processes that are new to the firm, not necessarily new to the market (Bloch, 2007).

Figure 5 compares the share of innovative firms in Norway with that of other European countries (as reported by the CIS4, the fourth version of the survey, undertaken in 2004). The measure 'share of innovative firms' is the number of firms that report having undertaken successful product or process innovation divided by the total number of reporting firms for the country in question. As in Figure 4, the Norwegian share is compared with those for other economies on an 'actual' and 'adjusted' basis, the latter comparison being adjusted for cross-national differences in industrial structure. Thus, if Norwegian firms are more innovative than firms in the other country, the 'adjusted' share will be above one or vice versa. The data in Figure 5 suggest that the share of innovative firms in Norway is comparable to that of several Southern European countries but lower than that of other high-income countries in Northern Europe with which it may more usefully be compared (particularly Sweden and Germany). Interestingly, and in contrast to R&D (Figure 4), the result does not appear to be sensitive to cross-national differences in specialization patterns.[11]

The Community Innovation Survey also contains important information about qualitative features of the Norwegian innovation system. As emphasized in the innovation literature (Lundvall, 1992; Van de Ven, 1999) innovation is an interactive phenomenon, and success depends on the ability of firms to cooperate with others and with customers (Lundvall, 1988; Von Hippel, 1988). The central importance of the latter follows from the simple insight that innovations that do not address customer needs often fail. Moreover, there is a good deal of customer-based learning that may benefit innovating firms. Figure 6 reports the share of firms that cooperate with others in innovation (based on data from the CIS). Norway, together with the other Nordic countries, scores especially high on this dimension. Norway also ranks high on the reported importance of producer–customer interactions in innovation (Figure 7).

Innovation is not only — or mainly — about inventing new things, but depends as well on commercial exploitation of the opportunities created by new knowledge in established as well as new industries and products (Schumpeter, 1934; Kline and Rosenberg, 1986; Fagerberg, 2004). One measure of a country's ability to identify, absorb and exploit new knowledge, often termed 'absorptive capacity' (Cohen and Levinthal, 1990), is the level of education among its population, particularly levels of higher education (Figure 8). Norway and other Nordic countries have substantially higher shares of tertiary-education degreeholders than is true of many other European economies. Another indicator of absorptive capacity is the level of adoption of important new technologies within an economy. Figure 9 compares the level of Norwegian adoption in 2005 of one such 'general purpose technology', personal computers, with that of other European nations, revealing that the Nordic countries, including Norway, display the highest rates of adoption for PCs. These indicators point to an important strength of the

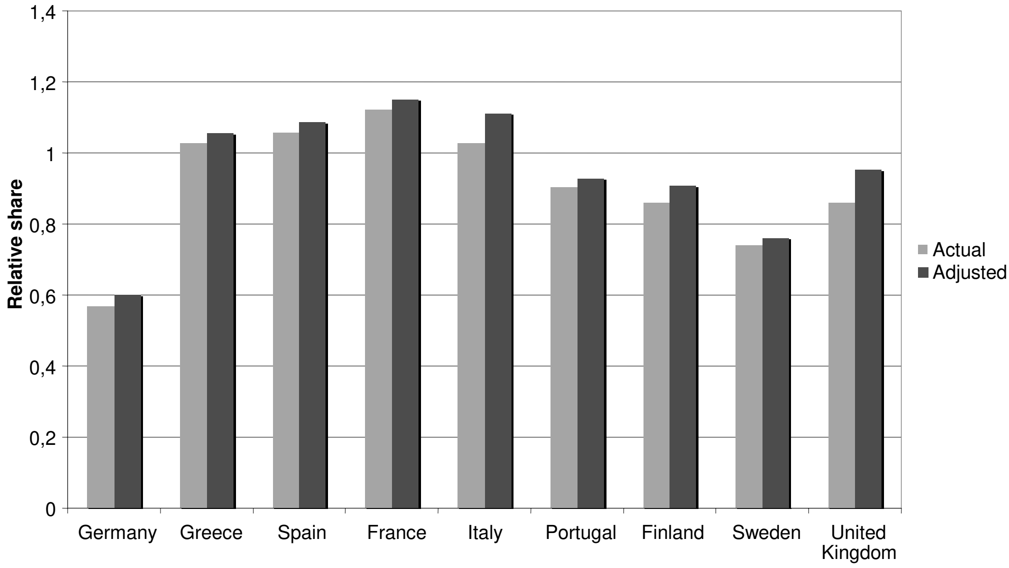

Figure 5. Innovative firms as a share of all Norwegian firms relative to other European economies, actual and adjusted for structural differences, 2004
Source: Eurostat (CIS 4)

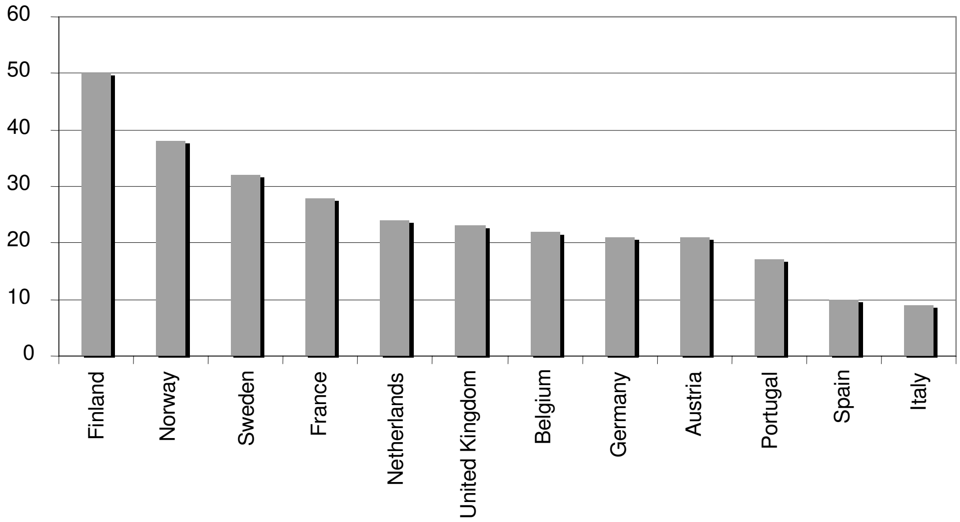

Figure 6. Share of innovative firms with cooperation arrangements on innovation activities, Norway and a reference group, 2001/2002
Source: CIS 3 (Eurostat)

Norwegian innovation system: its strong performance in knowledge diffusion and cooperation in innovation.[12] This characteristic of national innovation systems is typically not captured by conventional indicators of innovation inputs or outputs.

The Norwegian economy has generated strong growth in productivity, employment and income since 1970. At the same time, however, Norway invests an unusually low share of GDP in R&D, particularly within the business sector, and the CIS data also suggest that the level of industrial innovation in Norway is not particularly impressive, at least by comparison with other high-income economies in Northern Europe. Other characteristics of industrial innovation in Norway, however, such as the level of collaboration in innovation, producer–customer interaction, the qualifications of the labor force and the limited indicators on technology adoption, are relatively strong by comparison with most other European economies. These apparently contradictory indicators and findings underscore the need for a more detailed examination of the evolution of Norway's national innovation system.

The development of the Norwegian innovation system: historical co-evolution of sectors, institutions and policies

Norway's economic development has been characterized by the emergence over time of sectors with different approaches to innovation (Wicken,

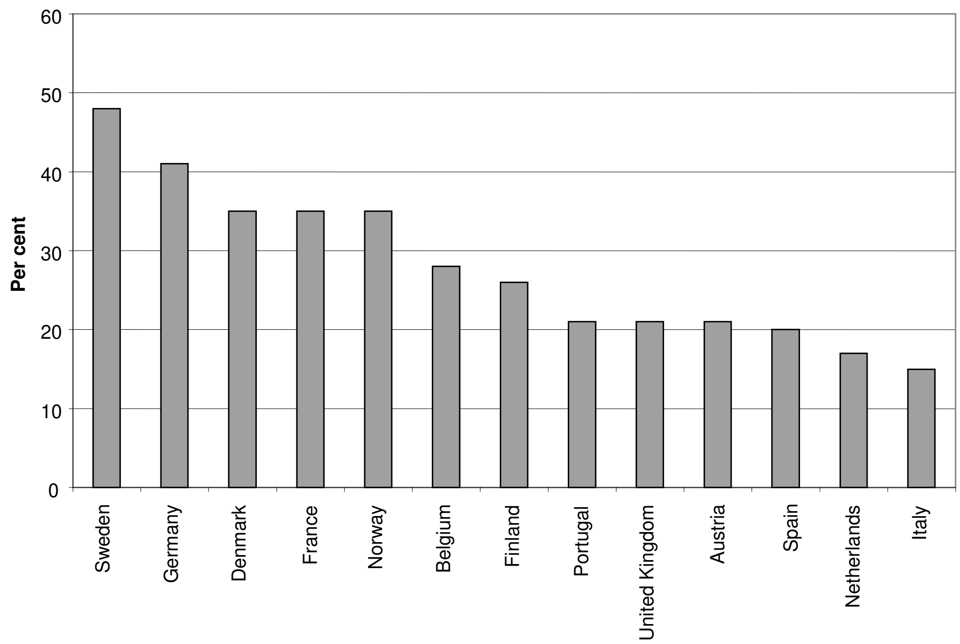

Figure 7. Share of innovative firms that rank customers as 'highly important' sources of information for innovation, Norway and a reference group, 2001/2002
Source: CIS 3 (Eurostat)

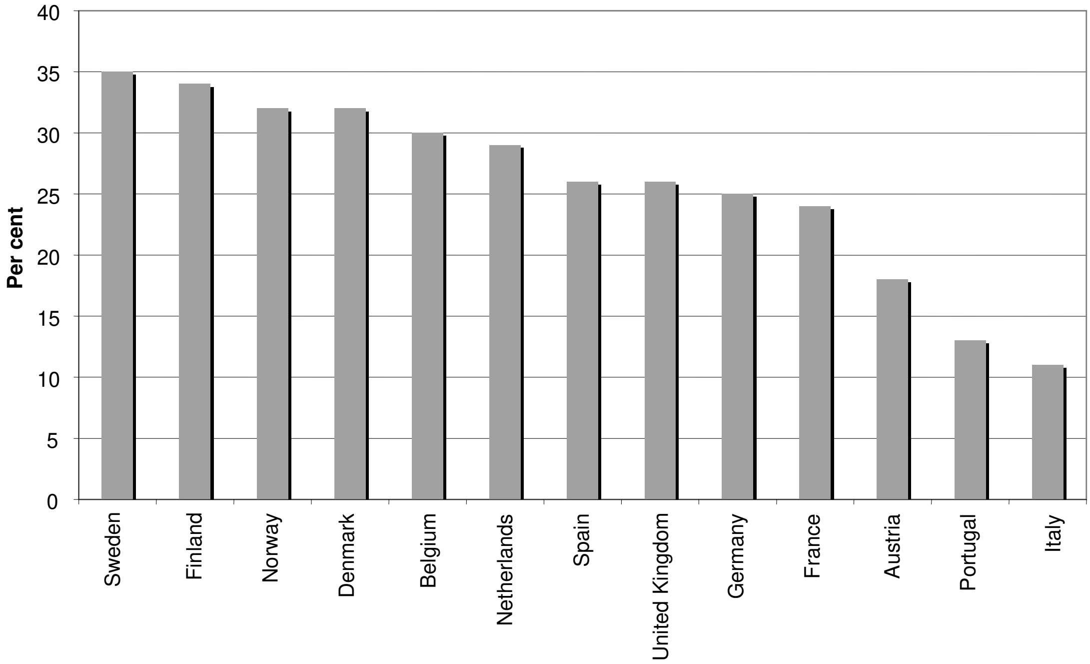

Figure 8. Percentage of population with tertiary education (age 25–64), Norway and a reference group, 2000–2004
Source: OECD (2006), Education at a Glance

2009a,b). The 'small-scale decentralized' development path, which dominated Norway until the early 20th century and remains economically and politically important, is characterized by small firms that invest little of their own funds in innovation-related activities. Beginning in the late 19th century, however, a sector characterized by large-scale, centralized enterprises, often financed by foreigners, expanded within Norway, based on the exploitation of opportunities in capital- and energy-intensive industries such as in metals, electrochemistry, and hydroelectric power. But as we note below, even the firms within these industries were slow to develop in-house R&D.

After the Second World War, an influential group of policy-makers, technocrats and academics — the 'modernizers' (see Box 1) — promoted the growth of a 'knowledge-intensive, network-based' development path characterized by R&D-intensive firms in 'new' industrial sectors such as ICT, relying on public investments in Norway's national R&D infrastructure of public laboratories and universities. In Norway, as in other high-income economies, these three development paths and corresponding sectoral innovation systems have coexisted, rather than one being succeeded historically by another. Norway thus is home to a diverse and complex 'ecology' of innovation systems, illustrated by the contrasting

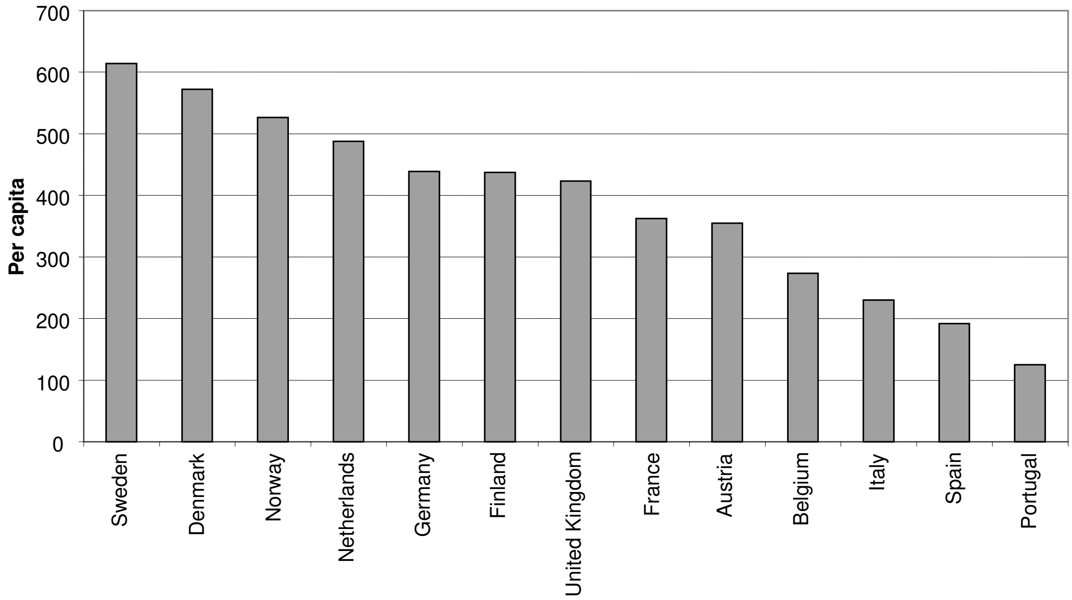

Figure 9. Penetration of PCs within the population, Norway and a reference group, 2005
Source: World Bank (World Development Indicators 2007)

Box 1. The 'modernizers'

Norway's dependence on natural resources has always been controversial within domestic politics. During the post-1945 period, a strong and politically powerful lobby of 'modernizers' gained political power and argued that a modernization of the industrial structure of the country in the direction of 'high-tech' industry, particularly ICT, was a must. The 'modernizers' were strongly influenced by the achievements of US and British scientists, military research facilities and 'high-tech' firms during and after the Second World War and wanted to create a similar dynamic in Norway by supporting military R&D, public research labs (particularly within ICT) and selected 'high-tech' firms. The national industrial research council (NTNF) and national defense research establishment (FFI), both established in 1946, were central institutional actors in the 'modernizing' network, along with other public and semi-public laboratories (Wicken, 2009b; Gulbrandsen and Nerdrum, 2009a).

The modernizers' economic and political agenda was widely accepted among policy-makers, and for several decades public R&D labs and selected high-tech firms, particularly within ICT, received substantial financial and political support from government (Wicken, 2009b). These policies produced several important inventions in military technology, computer software (e.g. the SIMULA language; see Sogner, 2009), computer hardware and telecommunications, including the GSM system for mobile telephony (Sogner, 2009). For a time, these investments generated substantial civilian spinoffs in the form of thriving 'high-tech' firms in the computer and telecommunication industries. However, the displacement within the global IT industry of dominant technologies such as minicomputers, the shift towards a more economically liberal political stance among Norwegian policy-makers, deregulation efforts and the intensified global competition in ICT that characterized the 1980s all undermined Norway's 'high-tech' industrial strategy. Many of the firms supported by these programs went out of business and today production of ICT products for the mass market has ceased in Norway (Sogner, 2009).

The attempt to make Norway a 'high-tech' leader thus ended in failure. The competences created by these policies in ICT technology, however, produced payoffs in other parts of the economy, particularly in the rapidly expanding oil and gas industry (Engen, 2009; Sogner, 2009). Hence, instead of substituting for resource-based industries, as the 'modernizers' envisaged, their efforts instead strengthened innovation and competitiveness within the resource-based sector.

examples of fish-farming, aluminium, and information technology, all three of which have played important roles in Norway through much of the 20th century.

At the beginning of the 20th century, the Norwegian economy relied extensively on external sources for new technologies. Technologies from foreign sources were adapted to Norwegian conditions by technically trained individuals, many of whom had been educated abroad. A national public research infrastructure evolved slowly in response to the needs of Norwegian firms and industries (Gulbrandsen and Nerdrum, 2009a), and initially gave priority to supporting established (and politically influential) industries, such as mining, fisheries and agriculture. A mining college was founded under Danish rule during the 18th century, and by the turn of the 20th century, Norway's primary industries lobbied successfully for the formation of public research institutes in agriculture and fisheries. Only with the emergence of the large-scale, capital-intensive industries of the early 20th century was Norway's technical university (NTNU) established (1910), nearly a century after the foundation of Sweden's technical university. Once established, NTNU became an important source of qualified personnel for industry, particularly Norway's scale-intensive, resource-based enterprises. Norwegian university scientists and engineers became active in industrial consultancy in the first half of the 20th century, and during the following decades Norway's research institutes, many of which are public (or semi-public), expanded their operations. Foreign sources of technology and capital also continued to play an important role in many of Norway's large-scale, resource-intensive industries

By the mid-20th century, Norway's national innovation system had acquired many of its current features. Norwegian firms were innovative in many respects and demanded highly educated labor. But they invested little in internal R&D. Instead they utilized 'localized search' (Nelson and Winter, 1982) in problem-solving, seeking technical knowledge from other firms, research institutes, public sources, academia, etc. Only when the search for solutions from external sources was unsuccessful did Norwegian firms invest substantially in intrafirm R&D. In-house R&D became more significant as some Norwegian firms approached the international knowledge frontier during the 1960s and 1970s. Nevertheless, through much of the 20th century, the dominant approach to innovation within much of Norwegian industry relied on interaction with other actors in the system, in combination with modest levels of investment in intrafirm R&D (Wicken, 2009a,b; Gulbrandsen and Nerdrum, 2009a).

Even today the strong tendency for Norwegian firms to engage with other partners in innovation, for example, to pursue collaborative innovation strategies, distinguishes Norway's innovation system from that of many other developed economies, as we noted earlier. In particular, as Lepori *et al* (2007) point out, the propensity of Norwegian firms to cooperate with public research institutes is high by international standards; 30–40% of the firms in several important Norwegian manufacturing industries report that they collaborate with public research institutes (Gulbrandsen and Nerdrum, 2009b), and user surveys indicate that the firms value such cooperation highly. These surveys also reveal that prior experience with such cooperation heavily affects both Norwegian firms' willingness to cooperate with public institutions and the value that they assign to such collaboration, illustrating the path-dependent character of these relationships (Nerdrum and Gulbrandsen, 2009).

The historically low level of investment by Norwegian firms in intrafirm R&D did not preclude technological innovation. The extensive structural changes that have occurred in the Norwegian economy during the last century have been accompanied by a stream of economically important innovations.

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For example, the rise of the large-scale, capital-intensive path of economic development in the early 20th century was based on the exploration of hydroelectric energy by Norwegian entrepreneurs such as Sam Eyde who, in a classically Schumpeterian fashion, developed a 'new combination' of knowledge, capabilities and resources (Wicken, 2009a; Gulbrandsen and Nerdrum, 2009a). The Norwegian oil and gas industry faced daunting challenges in producing oil and gas under conditions of unprecedented complexity and hazardousness, and developed new technological and organizational solutions (e.g. the CONDEEP platforms; see Engen, 2009). The Norwegian fish-farming industry also relied on a stream of important innovations in fish farming, processing, and disease control.

But none of these major innovations, which relied on well-developed engineering competences and highly competent labor, depended on large-scale intrafirm R&D programs. Indeed, many such innovations, which affected the entire production system of Norway's natural-resource industries, may not even be classified as innovations by CIS-type surveys that mainly focus on technological (product and process) innovations (Smith, 2004).

The previous section emphasized the contributions of institutions and politics to the path-dependent development of innovation systems, and the evolution of the Norwegian national innovation system clearly reflects the influence of political as well as institutional developments. For example, the continued existence and extensive government support for the 'small-scale, decentralized' path of industrial development in Norway was the outcome of intense political struggles during the interwar period (Wicken, 2009a). The resulting political commitments and institutions shaped the organization of the Norwegian fish-farming industry half a century later and continues to influence the development of that industry in modern Norway.

These policies, along with other characteristics of Norwegian fish-farming, have produced a structure that contrasts with some of those other countries, particularly Scotland, that entered the industry later. While in Scotland fish-farming is dominated by large firms, the Norwegian industry has a much more heterogeneous structure, in which a small number of large, increasingly global firms coexist with a large group of small, family-owned firms (Aslesen, 2009).

Another example of institutional persistence that had far-reaching consequences for Norwegian economic and technological development is the 'concession laws' that were adopted in the early decades of the 20th century. These laws were originally drafted to create a framework for national control of natural resources, specifically, hydroelectric power, and influenced the early years of Norway's aluminium industry (Moen, 2009). But as Engen (2009) notes, this regulatory heritage also influenced the development of Norway's offshore oil and gas sector more than half a century later. The technological and organizational development of the Norwegian oil and gas industry might well have followed a very different path that more closely resembled that in the offshore oil and gas industries in Denmark and the United Kingdom in the absence of the regulatory system created during the early 20th century for an entirely different sector.

Institutions and politics thus have exerted great influence on the development of Norway's national innovation system, and the Norwegian case is by no means unique. Previous work on national systems of innovation has devoted little attention to the historic co-evolution of industries, institutions, and politics, possibly because much of it examines 'snapshots' of various innovation systems at a specific point in time. One of the advantages of this historical, evolutionary perspective is that it advances our understanding of the roles played by institutions and politics in innovation.

Concluding remarks: the Norwegian 'paradox' revisited

Norway's economic performance has been characterized as a 'paradox' (OECD, 2007; Grønning *et al*, 2008). Productivity and income are among the highest in the world, even when the rents from the oil and gas sector are excluded from the calculations. But Norwegian R&D investment accounts for a small share of GDP by comparison with other industrial economies, and other measures of Norwegian innovation activity, although imprecise, also are not very impressive. How can this be explained?

Three interrelated aspects of Norwegian economic development are important in explaining this paradox. They are subsumed under the headings: innovation, path dependency, and policy.

Innovation

The broad perspective on innovation and long-run economic change employed in this paper highlights the important role that innovation has played in Norway's economic performance, although the characteristics of Norway's industrial base and the processes of innovation that it supports mean that much of this innovation has eluded straightforward measurement. Perhaps the most important factor in Norway's innovative performance has been the ability of Norwegian entrepreneurs, firms, and public sector actors to recognize opportunities, mobilize resources, adapt existing capabilities and develop new ones, and develop appropriate institutions and policies. The system's adaptability thus appears to be one of the important factors contributing to Norway's successful technological and economic development. This adaptability arguably reflects other social, cultural, institutional and/or political characteristics of Norway and other nations that we cannot pursue here but present promising lines for future research.[13]

Path dependency

Second, the historical development of Norway's national innovation system is characterized by strong path dependency. The Norwegian innovation system has been dominated by resource-based innovation. The development of new industries that are less closely linked to natural resources, in spite of considerable support from public policy, has been relatively unsuccessful in Norway. The failure of the 'modernizing' policies in Norway is less a result of active resistance from established firms in politically powerful sectors than a reflection of the continued vitality of innovation-led growth and productivity in those sectors (Castellacci *et al*, 2009). Norway's resource-based sectors have displayed considerable dynamism in developing knowledge and adapting to new challenges.

Policy

Third, as we pointed out above, institutions and politics have fundamentally influenced the development of Norway's industrial structure and its innovation-related activities. Arguably, path dependency is as much a political and institutional phenomenon as an economic one in Norway's national innovation system. The political and institutional factors that have been important in the Norwegian case nevertheless extend far beyond a narrow definition of science, technology and innovation policy, underscoring the need to employ a broad perspective in the study of innovation systems.

However successful Norway's economy appears to be today, its history of innovation and economic growth does not constitute a basis for complacency about the future, which poses significant challenges. Although the oil and gas sector will remain economically important, there can be no doubt that the period of rapid economic growth based on the exploitation of Norway's offshore oil and gas is approaching its end, and future growth will have to rely on other sources (OECD, 2008). A second important change is the end of the century-long era of cheap hydroelectric energy, the abundant supply of which led to the establishment of electrometallurgical and electrochemical industries in Norway. The future competitiveness of these Norwegian industries will depend on technological and organizational innovations that offset the advantages flowing to foreign firms with lower energy costs.

Thus, although natural resources may play an important role in Norway's future economic growth, maintaining the nation's strong performance will require an increase in the level and scope of innovative activity. Arguably, this need for expanded innovation holds not only for the areas of traditional strength but for the economy as a whole.[14] Hence, raising the share of Norway's overall firm population that is active in innovation, rather than focusing primarily on firms in 'high tech' sectors, is a natural target for innovation policy.[15]

Notes

1. This paper draws on a research project, 'Innovation, Path Dependency and Policy', financed by the Norwegian Research Council (KUNI program, project # 154877) and a book based on the research in the project (Fagerberg, J, D C Mowery and B Verspagen, eds. 2009). The economic support from the Research Council is gratefully acknowledged. Mowery acknowledges additional support from the National Science Foundation (Cooperative Agreement #0531184). The authors would also like to express their gratitude to the Centre for Advanced Study at the Norwegian Academy of Science and Letters in Oslo, which sponsored the 'Understanding Innovation Group' that included the authors, during the academic year 2007–2008 when this paper was written. An earlier draft of this paper was presented at the joint GLOBELICS –PRIME session, 'The Role of STI Policies for development', 24 September 2008, Mexico City, Mexico.
2. For a critique of a broad definition of innovation and the innovation system concept see Viotti (2002).
3. Norwegian economic history contains a number of examples of successful new initiatives that relied for their creation on foreign entrepreneurs, capital or markets. The establishment of Norsk Hydro, for example, although spearheaded by Norwegians, succeeded only because of support from foreign investors, and foreign investment and technology have played important roles in other important new industries in Norwegian history (Lie, 2005).
4. These include evolutionary economics (Nelson and Winter, 1982), new growth theory (Romer, 1990; Aghion and Howitt, 1992) and the literature on 'national systems of innovation' (Lundvall, 1992; Nelson, 1993; Edquist, 2004).
5. The countries included in the comparison are: Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom, i.e. the same as in Maddison (2003) referred to earlier.
6. Rents from oil and gas production has been around 15% of GDP in recent years (since 2000) according to Statistics Norway (Cappelen and Mjøset, 2009).
7. See Cappelen *et al* (2000).
8. The index is a normalized version of the familiar 'revealed comparative advantage' measure (RCA). The RCA is defined as the share of a specific sector in a country's GDP divided by the similar figure for the world as whole (or the area we are comparing with). The index, then, is (RCA–1)/(RCA+1) and varies between 1 (in which case the RCA measure is indefinitely large) and –1 (RCA equal to zero).
9. Norway's level of domestic R&D investment has more in common with other natural-resource based economies such as Australia and Canada than with its closest European

neighbors. In 2004, overall R&D investment accounted for 1.6–2.0% of GDP in these three countries, with industry accounting for about one half of the domestic R&D investment. Source: OECD.
10. The same methodology is used in Figure 5's depiction of firm-level indicators of innovative performance, based on the CIS data.
11. Hence, although Norway and Sweden are sometimes categorized as being similar in many respects (Katzenstein, 1985), the evidence in Figure 5 suggests some important differences in their national innovation systems.
12. Niosi (2002) characterizes the Norwegian system as 'diffusion-oriented'.
13. For an interesting discussion of some of these aspects in the case of Denmark see Lundvall (2003).
14. The Norwegian Government has recently (after this paper was written) published a new white paper on innovation (St. meld. nr.7, 2008–2009). In the white paper the government expresses great satisfaction with the current policies which tend to favor areas of traditional strength and in the resource-based sector.
15. In light of this it is disquieting to observe that in contrast to most other European economies, the share of Norwegian firms reporting that they were active innovators has declined during the first years of the new millennium (Castellacci *et al*, 2009).

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