1

Introduction: Innovation in Norway

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Norway was once one of the poorer countries in Europe. According to Maddison (2003), in 1870 Norway's 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.[1] Hence by the beginning of the twenty-first century, Norway had become one of the richest countries in the world.

How can such a remarkable episode of economic "catchup" 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 recently there has been a shift of focus towards intangibles such as knowledge or innovation, and several new theoretical frameworks have emerged. 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). This book employs these new theoretical and empirical approaches to examine the contributions of knowledge and innovation to Norway's economic development.

Our emphasis on knowledge and innovation as essential factors for economic prosperity uses a broad definition of these concepts. Thus we consider more than the organizations such as 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, economic growth benefits less from the creation of knowledge per se than from its 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 knowledge or technology is especially important for small countries such as Norway, whose contribution to the global pool of new knowledge necessarily will be dwarfed by the potential contributions to Norway's economic growth from exploitation of this pool. Second, in Norway as well as elsewhere, considerable learning and innovation occur beyond the boundaries of organizations created specifically to support innovation (Lundvall 1992, 2007). Ignoring the contributions to economic prosperity from these "non-formal" innovation-related activities may create 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), a broad perspective toward the understanding of innovation is especially important in examining nations such as Norway, with a pattern of specialization that differs significantly from that of most other high-income economies.

These arguments strongly suggest that a few quantitative indicators of innovative performance are insufficient for understanding national innovation systems and providing policy advice. Instead, it is necessary to explore the innovation dynamics in leading economic sectors, investigate the interaction between the firms in these sectors and the "knowledge infrastructure" of the country, and assess the role of policy in this context. We adopt such an approach in this book. The first part of the volume (Chapters 2–4) examines the historical development of Norway's national innovation system, emphasizing the role of the Norwegian knowledge infrastructure and government policies toward innovation. The second part (Chapters 6–10) provides detailed studies of innovation within important sectors of the Norwegian economy, including aluminum, aquaculture, and the ICT sector. The third and final part (Chapters 11–13) analyzes the current structure and performance of Norway's knowledge infrastructure (public research institutes and universities) and policies for financial support of innovation-activities in industry. The remainder of this introductory chapter introduces the theoretical perspective applied in this book, provides some basic descriptive and comparative information on the modern Norwegian innovation system, summarizes the findings of the subsequent chapters and considers the lessons from this research.

INNOVATION, PATH DEPENDENCY, AND POLICY

The "national innovation system" (NIS) concept first appeared in work by Christopher Freeman (Freeman 1987), Bengt Åke Lundvall (Lundvall 1992), and Richard Nelson (Nelson 1993), and this analytic framework has since been extensively discussed in both scholarly and policy-analytic work. The NIS approach posits that innovation is an interactive activity that involves different various actors and organizations, and further argues that these patterns of interaction tend to be relatively stable over time and develop distinctive national features. Despite the popularity of the concept, however, very few studies have analyzed the development of individual national innovation systems in depth. Moreover, as Edquist (2004) points out, scholars disagree on how best to apply the innovation system concept to individual nations. Hence, some clarification on our use of the NIS approach is in order.

The term "innovation" is central to the NIS approach, highlighting its focus on the economic exploitation of knowledge, rather than only its creation. Schumpeter (1934) argued that innovation should be distinguished from invention, the creation of new ideas. New ideas may occur anywhere in the economic system, but attempts to carry these out into practice, e.g. commercialization, require specialized organizations suited to that purpose. In advanced economies such as Norway, private firms normally undertake this role, although other types of organizations, such as those in the public sector, can and do innovate. The bulk of the discussion in this volume, however, focuses on innovation within firms.

Schumpeter also provided a definition of innovation as a "new combination" of existing sources of knowledge and resources (Schumpeter 1934). Nevertheless, innovation is a cumulative phenomenon. It builds on existing knowledge, including past inventions and innovations, while at the same time providing the basis for new innovative activity in the future. Hence, choices made in the past influence innovation today, and contemporary innovation activity will similarly leave its imprint on the opportunity set facing future entrepreneurs. Thus, "history matters"—innovation is "path-dependent." Schumpeter's term, "new combinations," also points to the fact that innovations commonly depend on many different types of new and existing knowledge, capabilities, and resources, not all of which may reside within a firm. In many cases, knowledge, capabilities, and the like must be acquired from other "external" actors, including firms, research laboratories, universities, or individuals. Thus, although innovation primarily occurs in firms, it is at the same time an interactive process, in which many different social agents within the public and private sectors, may be involved (Lundvall 1988, 1992; van de Ven 1999).

The importance and extent of path dependency within innovation processes have been emphasized and debated in a large literature (Arthur 1989, 1994; David 1986; North 1990; Grabher 1993; Pierson 2000; Martin and Sunley 2006; Liebowitz and Margolis 1994, 1995). Evolutionary approaches to the analysis of innovation, such as those utilized in this volume, emphasize variety creation, adaptation, selection and retention, all of which are linked to time and path dependence. At any point in time many new ideas emerge, but only those that (at the time) are sufficiently well adapted to the selection environment are likely to be applied and form the basis for continuing adaptation and improvement. The introduction of an innovation is associated with the 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.

Although Schumpeter emphasized the broad similarities among these evolutionary processes across time and economic sectors, there are also important differences among industries or technological fields in the characteristics of their "sectoral" innovation systems (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 for example 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).

Sectoral innovation systems are characterized by well-defined knowledge bases, as well as contrasting patterns of evolution and industrial dynamics. A national system of innovation consists of firms in many different sectors operating within by a common (national) "knowledge infrastructure" and a common institutional and political framework. Hence institutions, governance, as well as politics, are relevant to the analysis of national systems of innovation (Pierson 2000; Whitley 2002). Institutions or "rules of the game" (North 1990) are difficult and costly to establish but facilitate economic interactions once adopted. Hence, institutions may be an important source of path dependency in their own right (North 1990). This may also hold for policies, which often tend to be "remarkably durable" (Rose 1990). For example, the system of "national concessions" in Norway's development of its natural resources was important for both aluminum in the early twentieth century and oil and gas in the 1970s, as Chapters 6 and 7 point out.

Since national innovation systems include firms belonging to different sectoral systems, the sectoral composition of a given national economy influences the operation and structure of its national innovation system, even as the national innovation system affects the performance of its constituent sectoral systems. In small, open economies such Norway that are highly specialized in a small number of sectors, this relationship between the sectoral and the national level is powerful, and we devote considerable attention to the interaction between the sectoral and national innovation systems within Norway in this volume. The relationship between sectoral and national innovation systems is a coevolutionary 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 at the same time the latter characteristics influence the subsequent evolution of the national economy (including its sectoral composition).

The national innovation system also is a selection environment for new entrepreneurial ventures, and path-dependency influences this selection environment. 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 Norway's innovation system for this reason has provided little support for new, knowledge-intensive sectors.[2] 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. 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).

It is also unrealistic to portray the knowledge infrastructure, entrepreneurs, and the politicians within even a relatively small nation such as Norway as monolithic. Among other things, the democratic political system of Norway has supported the growth of different political groups with conflicting perceptions of the economic future that Norwegian entrepreneurs have exploited to gain political and financial support for new undertakings. Chapters 2–4 describe the rise of a group of "industrial modernizers" in postwar Norway who exercised considerable power within the Norwegian government and state-owned industry. Although some of their efforts, particularly the attempt to create national "high-tech" champions based on ICT, met with limited success, they enjoyed considerable political and economic support for decades. The "rise and fall" of Norway's postwar policies of industrial modernization provide a fascinating example of the complex interactions among major stakeholders in the Norwegian economy and knowledge infrastructure that gave rise to self-reinforcing processes and policy intervention that were also influenced (and sometimes checked) by external events.

AN OVERVIEW OF THE NORWEGIAN INNOVATION SYSTEM

In common parlance, 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 the industries typically defined as "high-technology."

Figure 1.1 compares Norwegian GDP per capita (measured in purchasing power parity) with regional GDP per capita in Western Europe.[3] The thin line

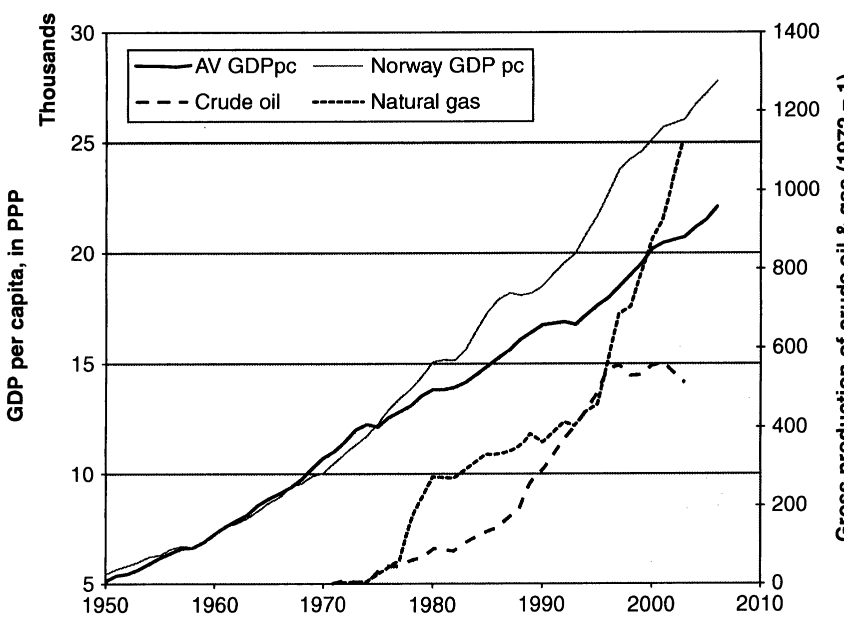

Figure 1.1. Norwegian economic growth and the rise of the oil and gas sector, 1950–2007.

Source: GGDC Total Economy Data Base (www.ggdc.net).

shows the Norwegian level, 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 much 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 the offshore oil and gas fields in Norwegian waters that began production in the early 1970s (the two dotted lines in Figure 1.1 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 during from 1975 onwards. As a result, Norwegian GDP per capita soared.

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, its development opened up a huge market that Norwegian manufacturing and services firms were well placed to exploit. 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 Chapter 7). In the Netherlands, another small open economy, oil and gas production was associated with deindustrialization, the so-called "Dutch disease." In Norway, however, the growth of the oil and gas sector benefited domestic manufacturing industry, output from which grew more rapidly than otherwise might have been the case (Cappelen *et al.* 2000). The rapidly increasing tax income from the oil and gas sector also enabled Norway's government to pursue a more expansionary fiscal and monetary policy than the more austere policies elsewhere in Western Europe during the 1980s and 1990s. As a consequence, Norwegian rates of labor force participation and economic growth were consistently higher—and unemployment markedly lower—than in Western Europe as a whole.

After a quarter-century of rapid growth, Norwegian GDP per capita was approximately one quarter higher than the West European average. However, only about one half of this difference can be explained as rents from oil and gas production.[4] Thus Norwegian GDP per capita is above the average for Western Europe even when the direct effects of oil and gas are removed from the data. Assessing the exact contribution of oil and gas to Norwegian economic growth is beyond the scope of this book. But its impacts on the Norwegian innovation system were substantial, and receive considerable attention in subsequent chapters.

Although oil and gas now appears to be the most economically important Norwegian resource-related industry, Norway's economic development historically has relied on the exploitation of a number of rich natural resources. Most of these were related to the geography of the country, such as activities related to the sea (fishing, shipping, and related industries), and the opportunities created by Norway's mountainous terrain for mining and production of hydroelectric power, which provided the basis for the nation's electrometallurgical and electrochemical industries. Although these sectors now account for a smaller share of Norwegian GDP than in previous periods, they remain 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 1.2[5] 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). It shows that in addition to its large oil and gas, sector, Norway remains highly specialized in its areas of traditional strength, particularly fisheries, shipping

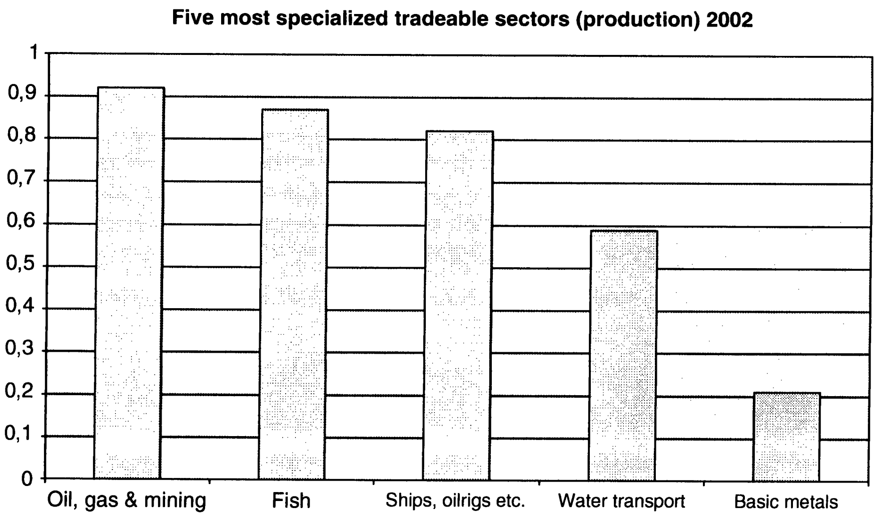

Figure 1.2. The five leading areas of Norwegian specialization, based on production of tradable goods and services in 2002.

Source: GGDC 60 Industries Data Base (www.ggdc.net).

and related industries. During the second half of the twentieth century, Norway also pioneered the development of fish-farming, and the nation remains among the global leaders in this industry. As we noted earlier, the shipbuilding industry that formerly supported Norway's fisheries and shipping sectors 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 book and the topic of long-running policy debates in Norway. One view of the role of technology in economic growth argues that a strong high-technology industrial base (consisting of ICT, biotech, new materials, pharmaceuticals, and selected other industries) is necessary for continuing prosperity. As several of the chapters in this volume show, however, Norway's resource-based sectors (aluminum, oil and gas, and fish-farming) have for decades been highly innovative, drawing on domestic 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 thirty years is its high rate of labor productivity growth, which has averaged more than 2.5 percent per year since 1975 (OECD 2007). Norway's strong economic performance, however, has been associated much lower levels of R&D investment and measured innovative activity than in most other high-income European economies. Figure 1.3 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 percent 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. Most of the countries whose R&D intensity in Figure 1.3 exceeds that of Norway have a much higher industry-financed share.

Although R&D spending is a widely used indicator of innovation, it is only one of several important contributing factors in successful innovation; the importance of R&D investment relative to other factors varies substantially among economic sectors (Fagerberg *et al.* 2004). Does the unusual (relative to other European economies) Norwegian pattern of specialization explain its lower levels of R&D investment? For example, it is possible that the sectoral innovation systems in Norway's fields of specialization operate differently, or rely on sources of innovation that themselves require lower levels

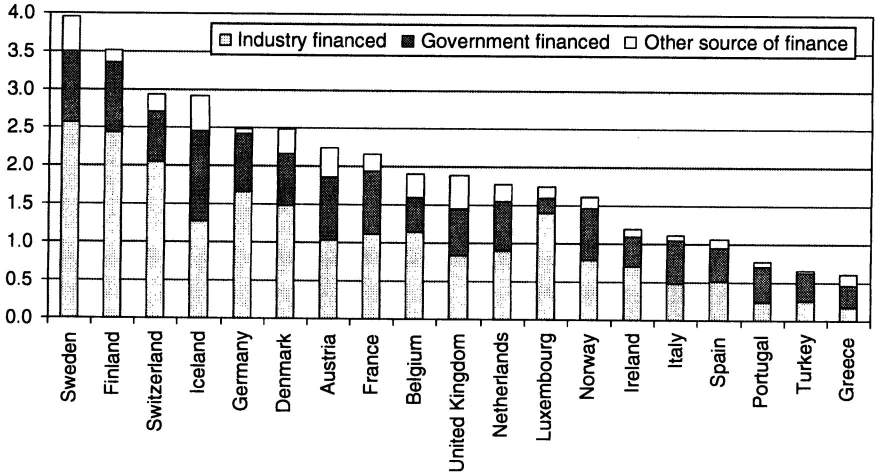

Figure 1.3. R&D as a percent of GDP: Norway and a reference group of European economies, 2004.
Source: OECD.

of R&D investment than in other European economies. One approach to examining this question controls for cross-national differences in economic specialization patterns when comparing R&D investment levels across countries. Figure 1.4 compares the share of value added accounted for by Norway's 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").[6] If Norwegian firms on average invest more in R&D than firms in the same sectors in the other country, the ratio will be above one and vice versa.

The results reported in Figure 1.4 indicate that Norway's economic structure does influence its low economy-wide 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 do foreign firms in the same sectors. The finding that the low level of Norwegian R&D is influenced by the pattern of specialization is corroborated by the results of other studies (OECD 2007), and by evidence from other high-income economies that are specialized in natural resource production.[7] Nonetheless, as was 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, including the

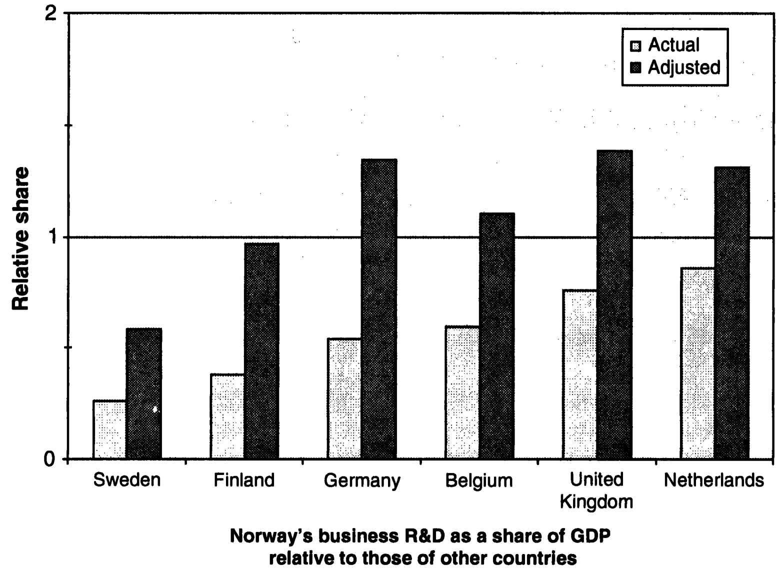

Figure 1.4. Norway's share of business R&D in GDP relative to those of other countries, actual and adjusted for structural differences, 2001/2002.

Source: Authors' calculations based on OECD and Eurostat data.

adoption and modification, as well as the creation, of technology. One source of data on a broader set of innovation-related activities that we use extensively in subsequent chapters is the Community Innovation Survey (CIS), covering firms 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.

Figure 1.5 compares the share of innovative firms in Norway with that of other European countries (as reported by the fourth version of the CIS survey undertaken in 2004, "CIS4").[8] 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 the previous figure 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 share will be above one or vice versa. The comparative data in Figure 1.5 suggest that the share of innovative firms in Norway is comparable to that of a number of other Western European countries but significantly lower than Sweden and Germany. Interestingly, and in contrast to R&D (Figure 1.4), the

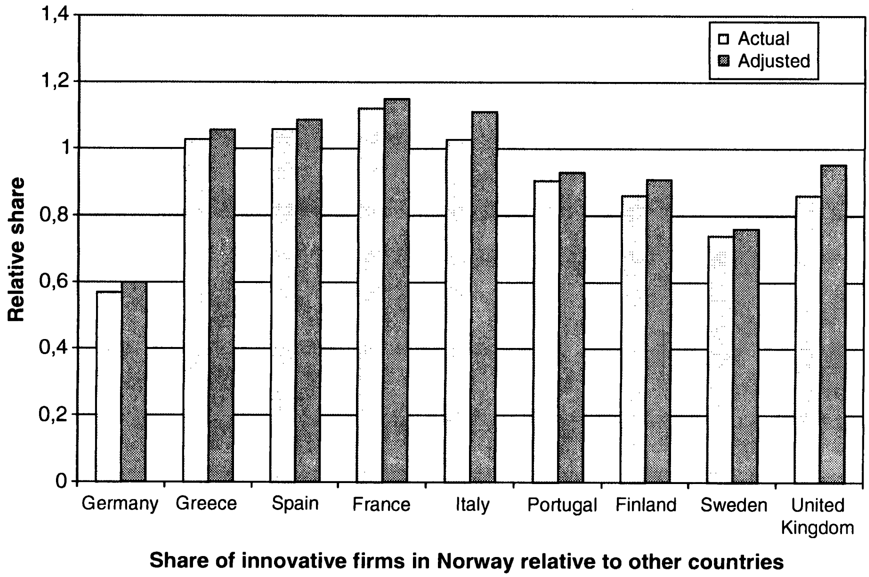

Figure 1.5. Innovative firms as a share of all Norwegian firms relative to other European economies, actual and adjusted for structural differences, 2004.
Source: Eurostat (CIS 4).

result does not appear to be very sensitive to cross-national differences in specialization patterns. Although Norway and Sweden are sometimes categorized as having similar economic policies and structures (Katzenstein, 1985), the evidence in Figure 1.5 suggests some important differences in their national innovation systems.

The Community Innovation Survey also reveals important information about other qualitative features of the Norwegian innovation system that are discussed in more detail in Chapter 5. The interactive nature of innovation means that success in innovation depends on the ability of firms to engage in innovation cooperation and interact with customers (Lundvall 1988; von Hippel 1988). The evidence indicates that Norwegian firms resemble those in other Nordic countries in their relatively high levels of cooperation with other firms and organizations in innovation. Firms in Norway and other Nordic countries also tend to value the role of customers in innovation more highly than do firms from other European countries.

Innovation is not only—or mainly—about inventing new things, but depends as well on commercial exploitation of the opportunities created by new knowledge (Kline and Rosenberg 1986, Fagerberg 2004). One measure of a country's ability to identify, absorb and exploit new knowledge, often

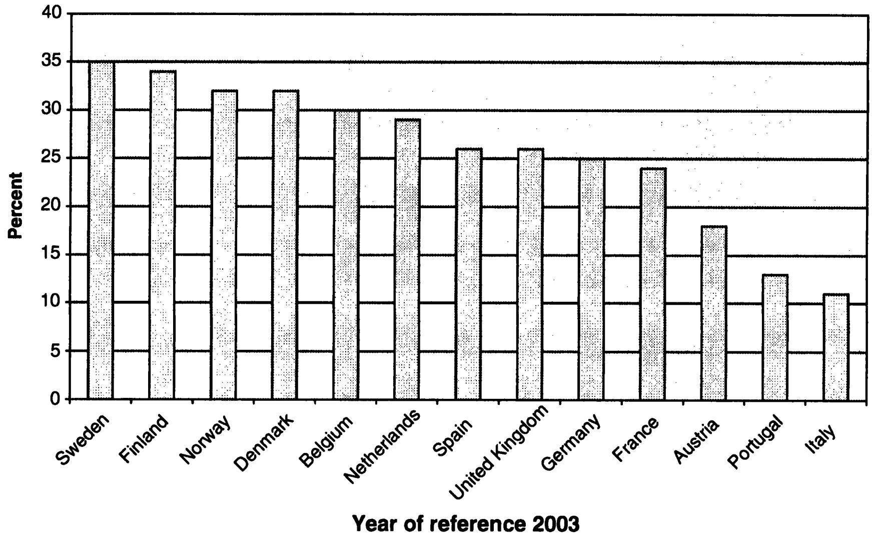

Figure 1.6. Percentage of Population with tertiary education (age 25–64), Norway and a reference group, 2000–2004.
Source: OECD (2006), Education at a Glance.

termed "absorptive capacity" (Cohen and Levinthal 1990), is the level of education among its population, particularly levels of higher education (Figure 1.6). 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 1.7 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 various indicators point to an important strength of the Norwegian innovation system, its strong performance in knowledge diffusion and cooperation in innovation. This performance characteristic is typically not captured in conventional indicators of innovation inputs or outputs.

The Norwegian economy has generated strong growth in productivity, employment and income since 1970, and this performance reflects more than the effects of oil and gas. At the same time, however, Norway has an unusually low share of R&D in GDP, particularly in the business sector, and the CIS data also suggest low levels of industrial innovation in Norway by comparison with some other high-income European economies. Other characteristics of industrial innovation in Norway, however, such as the level of collaboration

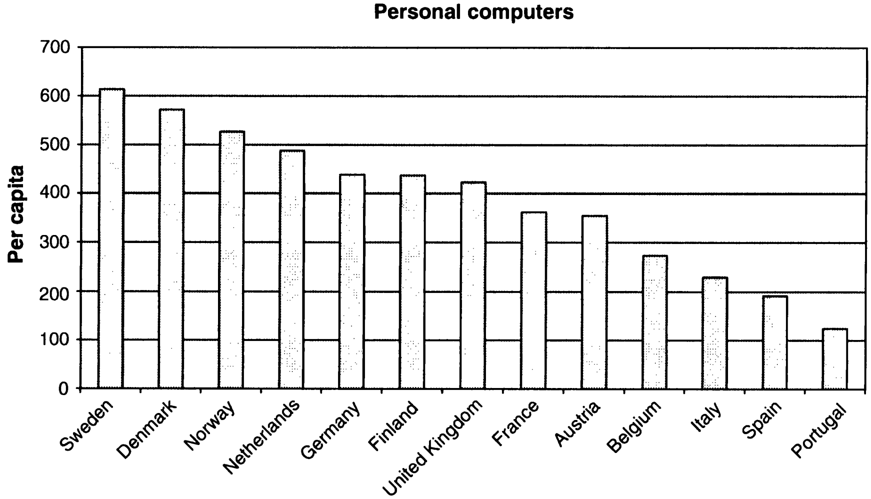

Figure 1.7. Penetration of PCs within the population, Norway, and a reference group, 2005.

in innovation, the importance of customers as sources of information for innovation, the high qualifications of the labor force and the limited indicators suggesting good performance in 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 analysis of sectors, institutions, and economic dynamics to provide greater insight into the characteristics of the Norwegian innovation system. The remainder of this volume presents a collection of such studies, and we summarize their key findings in the next section.

NORWAY'S INNOVATION SYSTEM: HISTORICAL DEVELOPMENT AND CURRENT STRUCTURE

Part 1 provides an overview of the Norwegian national innovation system and the chapters in this volume that discuss various aspects of the system's development and performance. Most of the chapters in this volume adopt a historical perspective. This approach is essential to an understanding of the current structure and performance of Norway's innovation system, since industries and firms co-evolve with the public research infrastructure, institutions and policy. The evolving industrial structure and firm characteristics help shape a nation's knowledge infrastructure and innovation policy, and the emergent policy framework and infrastructure in turn influence the survival of existing and new industries and firms. Chapters 2–5 provide an overview of the development of the Norwegian innovation activity, public research infrastructure, policies and support schemes. Part 2 (Chapters 6–10) presents detailed studies of the development of the innovation systems of important sectors within Norway's industrial structure, while the third part of the volume (Chapters 11–13) analyzes Norway's contemporary public R&D infrastructure and R&D subsidies.

The development of the Norwegian innovation system

Chapter 2 develops a broad conceptual framework for understanding the historical development of the Norwegian innovation system, arguing that Norway's economic development has been characterized by the emergence over time of industrial systems with different approaches to innovation. The *small-scale decentralized* development path is characterized by small firms that invest little of their own funds in innovation-related activities. In contrast, *large-scale, centralized enterprise* is dominated by organizations that seek to exploit economies of scale and scope in capital-intensive industries in which foreign investment has been prominent in Norway. As we note below, however, even the firms within these industries historically were slow to develop in-house R&D. Finally, the *knowledge-intensive, network-based* development path is characterized by R&D-intensive firms in "new" industrial sectors that are closely linked to the 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 coexist, 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 examples of aquaculture, aluminum, and information technology, all three of which have played important roles in Norway through much of the twentieth century.

Complementing this historical overview, Chapters 3 and 4 respectively discuss the development of Norway's public research infrastructure and the changing structure of public policy toward innovation in Norway. Norway was a European "latecomer" in developing a national university system, particularly in the technical field. Norway instead developed a public research infrastructure during the late ninetieth and early twentieth centuries as a piecemeal response to changing industrial needs. Inevitably, this process of institutional development gave priority to supporting established (and politically influential) industries, such as mining, fisheries, and agriculture.

Specialized research and higher education facilities devoted to these industries were established in Norway before the foundation of the Norwegian Technical University in 1910. The latter, once established, became an important source of qualified personnel for industry, particularly the scale-intensive, resource-based enterprises that played an important role in the Norwegian economy beginning in the early twentieth century. Nevertheless, the firms within Norway's large-scale industries rarely performed much in-house R&D. This does not mean that they did not innovate, but to the extent they did so they relied primarily on experience, the qualifications of their personnel and the exploitation of external knowledge, rather than on R&D within the firm.

Chapter 5 provides a more detailed examination of the structure and innovative performance of Norwegian firms in industry and services, comparing these dimensions of the national innovation system with those of other European innovation systems. Using innovation indicators derived from the Community Innovation Survey, the chapter develops a sectoral taxonomy of Norwegian innovation, and examines the sectoral patterns of industrial dynamics. The portrait of innovative activity within Norwegian industry that emerges from the analysis suggests that the three "developmental paths" outlined in Chapter 2 retain some influence on the modern Norwegian innovation system, although these historical "fingerprints" are somewhat blurry. From an international perspective, the Norwegian "resource-based innovators" are the most salient part of the innovation system, showing a relatively strong focus on process innovation, and production-oriented innovation motives. Nevertheless, as in most other industrial economies, the "science-based innovators" form the sector that exhibits the highest levels of innovation effort, measured in terms of inputs and outputs. Perhaps surprisingly, the "science-based innovators" are also the group of industries that show the highest level of firm concentration, the lowest level of dynamism and structural change. Chapter 5 also notes that the most recent CIS data indicate that the innovative performance of both the "science-based innovators" and "resource-based innovators" in Norway declined somewhat during the 2001–2003 period. This finding suggests that the long-term challenges faced by Norway could be substantial and raises questions both about the results of Norwegian government policies to support innovation (see below for further discussion).

Sectoral systems of innovation in Norway

As we noted earlier, during the first half of the twentieth century, Norwegian firms did not invest heavily in in-house R&D but relied mainly on external sources for knowledge. After 1945, however, firms in the scale-intensive sector began to invest more heavily in the development of their technological capabilities. Chapter 6 illustrates how firms in the Norwegian aluminum industry, which initially were both economically and technologically dependent on foreign firms, gradually changed course, largely as a result of a changing international competitive environment, and began to rely on Norway's public research infrastructure, which in response improved its capabilities in this area. According to industry representatives cited in the chapter, Norwegian aluminum firms now are now among the most technically advanced producers in the global aluminum industry.

Norwegian oil and gas firms, another scale-intensive, capital-intensive and resource-based industry, initially did not invest extensively in developing their knowledge base through R&D, relying instead on recruitment of qualified personnel and the purchase of R&D and engineering services (see Chapter 7). In addition, the early development of the industry in Norway (like aluminum) relied heavily on foreign firms. But the sheer size of the sector, along with the technological complexity of its activities, created a large market for Norwegian engineering firms and knowledge-intensive business services of all kinds. Much of this consulting and engineering support was provided by the public research infrastructure, particularly the institute sector. Only after a severe external shock, in the form of a collapse in the price of oil during the first half of the 1980s, did Norwegian oil and gas firms begin to develop a more strategic approach to R&D. Among other things, this strategic approach led to a joint public–private research effort (NORSOK) aimed at substantial reductions in the costs of offshore oil exploration and production in Norway. Chapter 7 argues that NORSOK spurred private R&D investment by Norwegian oil and gas firms, but private R&D investment has begun to exceed public R&D spending in the sector only since 2001.

Chapter 8 examines aquaculture, an industry in which Norwegian entrepreneurs and relatively small firms, many of which were in the fisheries sector, have pioneered in the development of new technologies for raising fish and other sources of seafood. The industry's location in coastal and northern Norway, its roots in the politically salient fisheries sector, and the small-scale, decentralized and entrepreneur-driven character of the industry all contributed to the development of government policies that promoted the industry while attempting to protect its decentralized, small-scale characteristics. These policies, along with other characteristics of the Norwegian industry, have produced an aquaculture industry structure in Norway that contrasts with those of other countries, particularly Scotland and Chile, that entered the industry later. Persistent financial problems among the smaller firms in

Norwegian aquaculture nevertheless have led to a less restrictive regulatory framework, and the industry has been restructured through mergers and acquisitions. The modern Norwegian aquaculture industry now has a heterogeneous structure, characterized by a small number of large, increasingly global firms that coexist with a large group of small, family owned firms. The origins of the aquaculture industry in the "small-scale, decentralized" developmental path remain apparent in the characteristics of innovation within the sector. Norwegian aquaculture innovation remains important and continues to be dominated by a combination of trial and error methods and exploitation of external sources, among which the Norwegian public research infrastructure has played a central role.

Science-based industries, such as ICT (discussed in Chapter 10), pharmaceuticals, and more recently biotechnology, are widely regarded as cornerstones of advanced-economy national innovation systems. Chapter 9 discusses the development of Norwegian biotechnology, a science-based industry that has received much attention from policymakers throughout the industrial world. Nevertheless, Norwegian firms have yet to achieve major commercial success in this industry, and have not developed regional agglomerations of the type commonly regarded as a defining (and essential) characteristic of a strong biotechnology industry. As the chapter points out, Norway may develop an alternative approach to the development of biotechnology, based on the expertise of Norwegian firms in some areas of marine and animal biotechnology. Interestingly, one of the strengths of Norway's biotechnology industry appears to be in segments such as marine biotechnology, that are rooted in Norway's "small-scale decentralized" resource-based industries (e.g. fisheries, aquaculture, animal breeding).

Although neighboring Sweden and Finland are home to global leaders in ICT (Ericsson and Nokia), Norway is very weak in this industry, as Chapter 10 recounts, in spite of lengthy and costly government support for the development of Norwegian ICT from the 1950s through the 1980s. These promotional policies for ICT were supported by a politically powerful group of technocrats, the so-called "modernizers" (see Chapters 2–4), promoting the development of "national champions" in this area. This strategy relied on Norwegian firms' commercialization of applications of ICT products developed from Norwegian military R&D programs instituted during the 1950s and 1960s. Despite the considerable funding and political support for these policies, however, and the early success of Norwegian IT firms such as Norsk Data, by the 1990s, Norway's ICT industry had nearly collapsed.

The current absence of large, multiproduct Norwegian ICT firms is especially incongruous in light of the significant technological contributions in telephony and radio communications technologies from Norwegian scientists and engineers. Norway pioneered many advances in mobile communications, for example, because of the nation's unusual geography and needs for such innovations, and the GSM technology that now is a global standard for mobile telephony was invented in Norway. Nevertheless, in spite of its commercial failings and the eventual collapse of many of the erstwhile national champions during and after the 1990s, Norwegian ICT firms became important suppliers of knowledge-intensive services and specialized products to other parts of the Norwegian economy, especially the oil and gas industry.

Contemporary institutions and programs supporting innovation in Norway

The historical development of Norway's economy and the supporting innovation system has left "fingerprints" on the contemporary Norwegian innovation system, as Chapter 5 points out. The third part of this volume examines the contemporary institutions and programs supporting innovation in Norway. Chapter 11 and 12 respectively discuss the role of Norway's universities and public research institutes in today's national innovation system. Chapter 11 uses data on research funding, publications and patenting to suggest that in Norwegian universities, similarly to those elsewhere in Europe, university–industry research collaboration has expanded since 1980. During the 1980s, the share of industry funding of university R&D increased, and the 1990s saw growth in PhD students finding work in firms, particularly in the oil-and gas industry, which now is the single largest employer of PhDs in Norway's private sector. The "University Act Amendments," passed in 2003, seek to encourage university patenting and licensing of faculty inventions, but too little time has passed since their passage to assess their effects with confidence.

Both Chapters 11 and 12 emphasize the importance of interaction and collaboration between universities and industry, the research institutes and industry, and between the research institutes and Norwegian universities. Indeed, the relatively close links between Norway's research institutes and universities, as well as the tendency for Norwegian firms to pursue collaborative innovation strategies, distinguish Norway's innovation system. For historical reasons, Norway's public research institutes have long played a particularly important role in spurring such cooperation. In fact, 30–40 percent of the firms in many Norwegian manufacturing industries report that they collaborate with public research institutes, and user surveys indicate that the firms on average value such cooperation highly (Chapter 12). The discussion in

Chapter 12 concludes that the Norwegian research institutes contribute to the nation's overall technological performance, and that the frequent criticism of the institutes for diverting resources from firms and universities is largely unsubstantiated.

The final chapter in Part 3 (Chapter 13) examines the operation and effects of Norway's R&D subsidy programs for industrial R&D. The chapter shows that Norwegian subsidies for industrial R&D (including EU-supported subsidies) mostly flow to relatively large firms with evidence of prior innovation activity and a proven ability to penetrate export markets. Conversely, firms with no history of innovation and smaller firms are less likely to receive such support, although EU subsidies do appear to support smaller firms' R&D to a slightly greater extent.[9] Taken as whole, however, public subsidies for industrial R&D in Norway appear to be more conducive to existing national strengths and paths of technological development than more novel avenues. Moreover, the chapter also demonstrates that Norwegian "research" subsidies stimulate additional private-firm investment in R&D, while the reverse is true for "development" subsidies, which tend to crowd out firms' own development expenditures. Thus, government financial support for "riskier" innovation-related activities seems to be more effective in expanding firms' R&D investment than support to projects closer to the commercialization stage. This is consistent what we should expect from innovation theory (Fagerberg *et al.* 2004). As projects approach the commercialization phase uncertainty typically is reduced, and firms are more likely to make the necessary investments with or without public subsidies.

Overall, the evidence in the chapters in Part 3 support a mixed verdict on the effectiveness of contemporary Norwegian government policies in supporting innovation and the development of new, knowledge-intensive activities. Norway has a substantial public-sector research infrastructure that has developed incrementally over the years in response to firms' needs. The Norwegian Research Council and government ministries dominate the funding of this infrastructure, and during the past decade, the links between Norwegian universities and the public research institutes have become closer in some areas, while in other areas, competition between the institutes and universities has intensified. Users of the public research institutes, especially firms in the resource-based sectors that play such an important role in the Norwegian system, appear to be broadly satisfied with the quality and accessibility of their services. Nevertheless, Narula (2002) argued that the Norwegian public research infrastructure, particularly the research institutes, is used less extensively by smaller, science-based firms in pharmaceuticals and biotech and that many firms in these industries rely on foreign sources for contractual R&D

services. However, reliance on foreign R&D should not necessarily be regarded as a problem. In many fields of science and engineering, the most advanced expertise will be available only from foreign sources, and interaction with foreign centers of excellence can contribute no less to innovation in areas where domestic competence is strong than in those with weaker capabilities. A potentially more serious issue is the evidence in Chapter 13 indicating that Norway's R&D subsidy programs may be biased against smaller firms and firms without prior innovation activity. There may be a danger that this support may mainly help "insiders" (and the established industries in which these firms are operating) rather than "outsiders" seeking to develop new knowledge-intensive activities.

CONCLUSION

Norway's economic performance has been characterized as a "puzzle" or "paradox" (OECD 2007; Grønning *et al.* 2008). Productivity and income are among the highest in the world, even without the extra contribution of the nation's successful oil and gas sector. 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?

One explanation posits that the statistical measures of innovation-related activities are poor proxies for the underlying phenomenon that we seek to measure. However, the premise that a close statistical relationship should exist between aggregate measures of R&D, innovation output and economic prosperity may also be flawed, particularly in a national innovation system in which resource-intensive industries are prominent. In fact, this premise assumes the existence of the "linear model" of innovation that was critically assessed by Kline and Rosenberg (1986), among other scholars. Rather than being an exogenous factor leading to predictable economic results, innovation is an endogenous phenomenon that is shaped through interaction between firms and their environments. Arguably, the evolutionary reasoning underlying Kline and Rosenberg's argument suggests that innovation is best studied as a historical process. 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, e.g. processes that systematically favor some types of activities (or solutions or ideas) while constraining others.

This historical and evolutionary perspective is useful in understanding the Norwegian innovation system and the Norwegian paradox. At the beginning of the twentieth century, the Norwegian economy relied on external sources for new technologies. Technologies from foreign sources were adapted to Norwegian conditions by technically trained people who often had received their education abroad. A national public research infrastructure evolved slowly in response to the needs of Norwegian firms and industries. A mining college was founded under Danish rule during the eighteenth century and around the turn of the twentieth century, Norway's primary industries exercised sufficient political influence to lead to the formation of public research institutes in agriculture and fisheries. Only with the emergence of large-scale, capital-intensive industries based on the exploitation of natural resources in the early part of the twentieth century was Norway's technical university established, nearly a century after Sweden's technical university was founded, and, with time, contract research organizations adapted to these industries' needs. As Chapter 3 noted, Norwegian university scientists and engineers became active in industrial consultancy in the first half of the twentieth century, and during the following decades Norway's research institutes, of which many are public (or semi-public), expanded their operations in response to users' needs. Foreign sources of technology and capital also played an important role in the establishment or expansion of many of Norway's large-scale, resource-intensive industries.

By the mid twentieth 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 exemplified the predictions of evolutionary theory (Nelson and Winter 1982) by using "localized search" in problem-solving, seeking technical knowledge from other firms, public sources, academia etc. Only when the search for solutions from external sources was unsuccessful did Norwegian firms invest substantially in intrafirm R&D. This investment in in-house R&D became more significant as some Norwegian firms approached the international knowledge frontier. In a number of Norway's resource-based industries, such as the aluminum and oil and gas industries, this exhaustion of external sources of technical solutions has occurred relatively recently, during the last few decades. Thus, the historically dominant approach to innovation within much of Norwegian industry throughout the twentieth century relied on interaction with other actors in the system, in combination with modest levels of investment in intrafirm R&D. As the analysis in Chapter 5 shows, this approach continues to leave its fingerprints on the national innovation system.

The historically low level of investment by Norwegian firms in intrafirm R&D does not imply that they did not innovate. Arguably, 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. For example, the rise of the large scale, capital-intensive path of economic development in the early twentieth century was based on the exploration of a new natural resource, hydroelectric energy, by entrepreneurs such as Sam Eyde, who in a classically Schumpeterian fashion, developed a "new combination" of knowledge, capabilities and resources. 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 (CONDEEP for example, see Chapter 7). The Norwegian aquaculture industry also relied on a stream of important, incremental innovations in fish farming, processing, and disease control. But none of these major innovations depended on large-scale intrafirm R&D investment. Arguably, innovations of this type, which affect the entire production system of natural-resource industries, may not be classified as innovations by the CIS-type surveys that focus on technological (product and process) innovations (Smith 2004).

The contributions in this volume emphasize the contributions of institutions and politics to the path-dependent development of innovation systems. Indeed, the path-dependent character of the evolution of the Norwegian national innovation system is a product of politics, as well as institutional development. For example, the continued existence and extensive government support for the "small-scale, decentralized" path of industrial development in Norway was in part the outcome of intense political struggles that during the interwar period produced an institutional regime that endures to the present day (Chapter 2). Moreover, this set of political commitments and institutional supports shaped the creation and organization of the Norwegian aquaculture industry half a century later (Chapter 10).

Another example of institutional persistence that had far-reaching consequences is the "concession laws" from the early decades of the twentieth century. These laws were originally drafted to create a system for national, democratic control of natural resources, specifically, hydroelectric power, and influenced the early years of Norway's aluminum industry (Chapter 6). But Chapter 7 notes that the same regulatory system was also crucial to 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 (as arguably was the case for the offshore oil and gas industries in Denmark and the United Kingdom that exploited the North Sea finds in their territorial waters) in the absence of the regulation system created during the early twentieth century for an entirely different sector. Hence, institutional innovation—and politics—exert a great influence over the development of national innovation systems, and the nature of this influence deserves more attention. Previous work on national systems of innovation has devoted little attention to these matters, possibly because much of it examines "snapshots" of various innovation systems at a specific point in time and lacks historical depth. Arguably, one of the advantages of the historical, evolutionary perspective applied in this study is that it advances our understanding of the roles played by institutions and politics in innovation.

The title of this volume, innovation, path-dependency and policy, points to three interrelated aspects of Norwegian economic development. First, applying a broad perspective to the study of innovation and long-run economic change, we recognize that innovation has been important factor in Norway's impressive 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 reflects other social, cultural, institutional and/or political characteristics of the nation that we cannot pursue here, but which also present a promising line of research.

Second, the development of Norway's national innovation system is a historical process characterized by strong path dependency. The Norwegian innovation system has been dominated by resource-based innovation, in contrast to those of other Nordic economies (both the Swedish and Finnish innovation systems have included resource-based sectors, but these now are much less dominant in each nation). The development of new industries that are less closely linked to natural resources, in spite of considerable support from public policy, has been much less successful. The lack of new, knowledge-intensive industries 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 these established sectors. Norway's resource-based sectors (both the large- and the small-scale examples) have displayed considerable dynamism in developing knowledge and adapting to new challenges. Finally, as we pointed out above, political and institutional changes in Norway have fundamentally influenced the structure of the economy and its innovation-related activities. Thus, in the case of the Norwegian innovation system, path dependency is as much a political and institutional phenomenon as an economic one.

Norway's history of innovation and economic growth should not be viewed as 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 close to its end and that future growth will rely on other sources. 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. These industries will have to compete on the basis of superior technology with foreign firms that benefit from lower energy costs. Hence, 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, and this goal should figure prominently on the policy agenda. Raising the share of the overall Norwegian firm population that is active in innovation, rather than focusing primarily on firms in "high tech" sectors, is an important target for innovation policies. In light of the importance of innovation for Norway's future economic growth, 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 (Chapter 5), underscoring the seriousness of the challenges facing Norway.

NOTES

1. The Western European countries included in this comparison are Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.
2. Based on interviews in selected Norwegian firms that invest in R&D, Narula (2002) concluded that large established firms in areas of traditional economic strength in Norway expressed greater satisfaction with the performance of Norway's national knowledge infrastructure than did small entrepreneurial firms in science-based sectors, such as pharmaceuticals and biotech. Narula interpreted

these interview-based findings as indicative of a "lock-in" phenomenon operating at the level of the Norwegian innovation system, which he argued was more supportive of innovation in established industries than for innovation in new industrial sectors, such as biotechnology or pharmaceuticals.

3. All data on GDP per capita and productivity used in this section are drawn from the GGDC total economy database, version of August 2007 (www.ggdc.net). The countries included in the comparison are Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom, e.g. the same as in Maddison (2003) refered to earlier.
4. Rent in this context is defined as return to capital above what is "normal" in the economy as a whole. Oil rents represented 14 percent of GDP in 2001, and Norwegian GDP per capita was about 27 percent above the Western European average.
5. The source for the data in Figure 1.2 is the GGDC 60 Industries Database (http://www.ggdc.net). The index (I) in the figure is the so-called "revealed comparative advantage" measure, normalized to vary between 1 and −1, e.g. $I = (r - 1)/(r + 1)$, where r is the ratio between a sectors share of GDP in Norway and the same share for the World as a whole.
6. 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 ratio of R&D performed in industry to GDP in Sweden (when compared 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. The same methodology is used in Figure 1.5's depiction of firm-level indicators of innovative performance, based on the CIS4 data.
7. 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 percent of GDP in these three countries, with industry accounting for about one half of the domestic R&D investment. In Finland and Sweden, in contrast, R&D as a share of GDP was in the 3.5–4 percent range, with approximately two thirds financed by industry. Source: OECD.
8. The data in the figure are similar to those analyzed in Chapter 5, but are drawn from a more recent edition of the CIS, and are adjusted for cross-national differences in industrial structure i.e. weighted by the structure of the country with which Norway is compared.
9. Moreover, it should be noted that the continuation of the "FUNN" scheme, the so-called "SKATTEFUNN," has been designed to benefit small, entrepreneurial firms to a larger extent than FUNN. The requirement in FUNN of cooperation with external research providers has for example been abolished. A recent evaluation of SKATTEFUNN concludes that the new scheme is successful in its aims (Cappelen *et al.* 2008).