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New regional industrial path development and innovation networks in times of economic crisis

Jan Ole Rypestøl ^a, Roman Martin ^b and Nina Kyllingstad ^{a,c}

^aDepartment of Working Life and Innovation, University of Agder, Kristiansand, Norway; ^bDepartment of Business Administration, University of Gothenburg, Gothenburg, Sweden; ^cNORCE Norwegian Research Centre, Kristiansand, Norway

ABSTRACT

This paper presents novel research on how exogenous shocks and economic crises affect innovation, knowledge networks, and new path development in regions. Conceptually, we take a regional innovation systems perspective which views new path development as the outcome of innovation and knowledge exchange between firms and other actors, facilitated by a common institutional framework. Empirically, we draw on interviews and network data from the oil and gas industry in southern Norway. Following a long period of prosperity, the industry was hit by the oil price shock in 2014 and entered an economic crisis. The findings suggest that the shock triggered the firms to commit even more forcefully to innovation and to expand their knowledge networks geographically. To cope with the crisis, they applied a variety of strategies, which can be associated with different forms of path development. We draw conclusions for innovation policy in the context of exogenous shocks and crises.

KEYWORDS

new path development; economic crisis; regional resilience; innovation network; regional innovation system; Norway

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O32; O33; R11; R58

1. Introduction: regional industrial path development and exogenous shocks

The evolution of regional industries has become a key issue in contemporary economic geography, often referred to by the umbrella term ‘(new) regional industrial path development’ (Hassink, Isaksen, and Trippel 2019; Grillitsch, Asheim, and Trippel 2018; Neffke, Henning, and Boschma 2011). Industries tend to evolve unevenly across geographical space, with some regions providing more favourable conditions for industrial path development than others. Regional industrial path development is typically linked to the quality and functioning of regional innovation systems (RIS), which consist of all organisations that are directly and indirectly concerned with innovation, their networks of interactive learning and knowledge exchange, and the institutional setting (Martin and Martin 2017; Isaksen and Trippel 2016; Zukauskaitė, Trippel, and Plechero 2017). In this literature, the reasons for industrial path development are typically seen as endogenous to the region. At times, however, exogenous events cause major threads to regional industrial path development. Examples of exogenous shocks include global economic crises,

CONTACT Roman Martin  roman.martin@handels.gu.se  Department of Business Administration, University of Gothenburg, Gothenburg, Sweden

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such as the financial crisis of 2007–08, which was followed by a major economic downturn that affected economies worldwide. Another example is the crisis caused by the outbreak of the coronavirus in 2019–20, which has required drastic governmental interventions into the functioning of societies and economies, and which has, in turn, triggered a global economic recession. These exogenous shocks place transformative pressures on regional industrial paths. As the literature on resilience shows, the way regional economies respond to exogenous shocks can differ (Bailey and Turok 2016; Boschma 2015; Bristow and Healy 2018; Simmie and Martin 2010). The ability of a region to adapt and recover depends on various factors such as the nature of the crisis, the capacity of governments to design and implement suitable policies, the innovative capacity of firms, and the nature and structure of inter-organisational networks. It also depends on different types of agency, including system- and firm-level agency (Isaksen, Jakobsen, and Njøs et al. 2019) as well as change agency (Grillitsch and Sotarauta 2020), encompassing Schumpeterian entrepreneurship, institutional entrepreneurship and place-based leadership. While an exogenous shock typically constitutes a threat to regional economies, it can also be turned into an opportunity for regions to renew their structures and functions and to develop new growth paths.

This paper deals with firms on a prospering regional industrial path and how they have responded to an exogenous shock and economic crisis. We take a RIS perspective by focusing on changes in firms' innovation activities, changes in their innovation and knowledge sourcing networks, as well as processes of new path development. Our study focuses on the oil and gas (O&G) industry in the Agder region of southern Norway, a strong regional industrial growth path in an organisationally thick and specialised RIS. Over the past decades, Agder has emerged as a major hub for producing upstream O&G drilling equipment and services worldwide. The region hosts several innovative manufacturing and service companies, which are heavily engaged in inter-organisational collaboration and knowledge exchange, and supported by an innovation-friendly regional institutional framework (including the NODE Cluster and a number of public research and educational organisations). After a long period of successful path development, accompanied by intense networking between local firms, the O&G industry faced a major economic shock in 2014, namely a drop in the price of oil, which led to a rapid decrease in global demand for O&G equipment. How such a shock can affect innovation activities, knowledge networks, and new regional industrial path development is the main question addressed in this paper.

The paper is organised as follows. First, we review the literature surrounding new regional industrial path development, the geography of knowledge sourcing and regional resilience. Second, we describe the research context and design, which draws on structured and semi-structured interviews with O&G firms in Agder before and after the oil price shock. Third, we analyse how the firms changed their innovation activities, their innovation networks, as well as their business and innovation strategies, in response to the crisis. Finally, we interpret our results and draw conclusions for further research on new regional industrial path development and for policy in the context of economic shocks and crises.

2. Theory: new path development and knowledge sourcing in times of crisis

2.1. Forms of (new) regional industrial path development and knowledge sourcing dynamics

The literature on economic geography is increasingly concerned with the issue of how industries in regions emerge and evolve over time. Combining evolutionary with institutional theories, this debate often takes place using the term (new) regional industrial path development (Isaksen and Trippel 2016; Hassink, Isaksen, and Trippel 2019). A regional industrial path consists of interconnected firms and related organisations in a region, specialised in a particular field, as well as their assets and capabilities. The development of regional industrial paths thus rests on the aggregated development of firms and related organisations and their assets (Chen 2022; Isaksen, Langemyr Eriksen, and Rypestøl 2020). The underlying mechanism that explains different forms of path development is typically related to knowledge dynamics, that is, the capacity of local firms to source, exchange, combine, and create knowledge in a collaborative effort, together with other actors both within and outside of the regional industrial path (Asheim, Isaksen, and Trippel 2019). In this context, there are typically five main forms of path development that can be distinguished, namely path creation, related and unrelated path diversification, path importation, path upgrading (sometimes also referred to as path modernisation), and path extension. A failure to ensure path extension can lead to a sixth form of path development, which is path exhaustion (Asheim, Isaksen, and Trippel 2019; Hassink, Isaksen, and Trippel 2019; Blažek et al. 2020).

Path creation is the result of radical change in industrial structures. It is often associated with knowledge-intensive activities, discoveries that stem from scientific research and the exchange of science-based knowledge. A regional influx of skills and firms that possess the necessary absorptive capacity and capabilities is also typical (Trippel, Grillitsch, and Isaksen 2018; MacKinnon et al. 2019). *Path diversification* stands for the development of a new industry based on related or unrelated combinations of knowledge and competencies. *Related* path diversification describes the fact that new paths can grow out of existing industries in a region and requires the combination of different types of knowledge. In line with the arguments of related variety and regional branching, the focus is on knowledge spillovers between firms which have different, but related, activities (Neffke, Henning, and Boschma 2011). *Unrelated* path diversification is the result of combining firms' existing competencies with new, unrelated knowledge. Recent studies have pointed out that exchanging knowledge with actors in initially-unrelated industries can lead to unexpected combinations, positively affecting industrial renewal (Grillitsch, Asheim, and Trippel 2018; Neffke, Henning, and Boschma 2011). *Path importation* entails the establishment of industries that are new to the region and imported from other locations (Grillitsch, Asheim, and Trippel 2018). This occurs by settling non-local firms, entrepreneurs, or highly-skilled labour from other regions. Thus, path importation is closely associated with an influx of knowledge and competencies from extra-regional sources (Asheim, Isaksen, and Trippel 2019; Martin, Aslesen, and Grillitsch 2018). *Path upgrading* indicates a significant change in an existing industrial structure based on new technologies or organisational innovation, which provides an existing path with a new direction (Asheim, Isaksen, and Trippel 2019). *Path extension* is

understood as a continuation of regional industrial structures, mainly realised via incremental innovations in existing firms and industries. Firms mainly learn through knowledge exchange within established inter-organisational networks (Isaksen 2015).

The sixth form of path development, *path exhaustion*, represents the decline of a previously-successful regional industry due to a negative lock-in (Blažek et al. 2020). The negative lock-in can be institutional, functional, or political in nature and is typically ascribed to an over-embeddedness or inward orientation of firms and other industry actors in the region (Hassink 2010). It can be the result of a lack of complementary knowledge in the region, which tends to reduce the possibility for interactive learning and knowledge. A lack of diversity and variety in the regional knowledge base increases the risk of negative lock-in and the exhaustion of regional industrial growth paths (Manniche, Moodysson, and Testa 2017; Martin and Rypestøl 2018). Further, firms with weakly-developed organisational learning practices and low absorptive capacity are more prone to lock into negative growth paths, in contrast to firms where learning is an integral part of their organisational capabilities (Isaksen and Trippel 2016).

From this discussion follows that the potential of a regional industry to adapt to an exogenous shock and overcome a crisis depends on the ability of local firms to adapt and innovate. This requires the sourcing and combining of knowledge from different organisations and from different geographical scales, which can, in turn, lead to different forms of new path development.

2.2. Regional industrial path development, shocks and resilience

The question how external shocks affect regional industrial path development is closely linked to the notion of resilience (Bristow and Healy 2020). The concept is often used to discuss the economic effects of shocks, respectively the *reactive adaption* or *adaptive capacity* of regional economies (Martin and Sunley 2015, 2020) or clusters (Suire and Vicente 2014; Henry, Angus, and Jenkins 2021). Shocks are thereby understood in contrast to continuous pressures on regional economies, resulting for example from technological change or globalisation, which materialise incrementally.

When it comes to consequences of exogenous shocks for regional path development, different growth trajectories are possible. Typically, a shock would trigger a period of recession where a growth path is pushed downwards and continues a trajectory that is inferior to the pre-shock state. Diminishing profits, job-losses, out-migration of skilled labour and lower innovation rates among firms can, in the worst case, cause a downward spiral that eventually leads to path decline and exhaustion (Blanchard et al. 1992; Blažek et al. 2020; Holm and Østergaard 2015).

However, shocks can also constitute an opportunity for regional economies to renew their structures and functions and to move to a new trajectory that is superior to the pre-shock state. In this scenario, regional economies would respond to a shock by reorganising around an upward-shifted path of development. An exogenous shock can trigger a shake-out process, where unproductive companies and procedures are wiped out, and skills and other assets are re-employed in more productive companies and in more productive ways. Such a process can be self-reinforcing, triggering entrepreneurship and innovation, and even leading to in-migration of skilled labour and the location of new firms to the region. Eventually, this can lead to an upward spiral and the

continuation on a growth trajectory that is superior to the pre-shock state. Thus, a shock may well trigger positive regional industrial growth dynamics in the form of path creation, path diversification or path importation.

The causes for regional differences in resilience are manifold. Factors that determine the adaptive capacity of regions are linked to different subsystems of a regional economy, including the industrial and business structure, the labour market, the financial system, the government system, and local agency and decision making capacities (Bristow and Healy 2018; Martin and Martin 2017). A common argument in the resilient literature is that a diversified business structure favours resilience, whereas specialisation in business activities undermines resilience (Martin and Sunley 2015). This is in line with the RIS argument that organisationally thick and diversified RIS, which are well-endowed with innovative firms and a critical mass of knowledge generation and support organisations, are well-equipped to counterbalance economic shocks (Asheim, Isaksen, and Trippel 2019; Hassink, Isaksen, and Trippel 2019), due to high potentials to source and combine knowledge from diverse sources and to create novelty through related variety. This is consistent with Bristow and Healy (2018), who find that regions with high innovation performance tend to be more resilient. In contrast, organisationally thick and specialised RIS that operate in a limited number of industries, typically backed by support organisations that are closely aligned with the region's industrial specialisation, can be argued to be less resilient. Firms tend to generate value from knowledge connections within the same area of specialisation, which supports incremental innovations. Due to a risk of cognitive myopia and different forms of lock-in (Hassink 2010; Grabher 1993), actors in such RIS are less capable of identifying, absorbing, and attracting knowledge in unrelated fields. This can prove problematic when the respective industrial path faces challenges in the case of external shocks and crises. Organizationally thin RIS are particularly vulnerable to exogenous shocks. They are home to few innovative companies and a low number of knowledge generation and support organisations, typically of lower quality. This implies that thin RIS, due to their lack of variety in industries and innovative firms, have a higher risk of tapping into path extension, or even path exhaustion (Isaksen 2015; Blažek et al. 2020).

Apart from characteristics of the regional economic and innovation system, the role of agency has become increasingly discussed in accounts on regional industrial path development and resilience (Bristow and Healy 2014; Jolly, Grillitsch, and Hansen 2020; David 2021). Specific agents react differently to regional economic shocks, and their diverging behaviours can lead to different outcomes when it comes to path development. Regional agents, including managers, entrepreneurs, workers, and policy makers, may anticipate certain developments and adjust their behaviours in expectation of a crisis, but they can also react to a shock and transform their behavioural strategies in response, and thereby drive change (David 2018; Rypestøl et al. 2021; Isaksen, Jakobsen, and Njøs et al. 2019). Then again, agency can also impede the adaptive capacity of regions by reproducing existing structures and functions and resisting to change (Bækkelund 2021).

In the following section, we study how an exogenous shock affected innovation activities, knowledge networks, and processes of path development in the O&G industry in Agder. The focus is on firms as key agents of change. We begin the empirical section with an overview of the research context and the method used to collect and analyse the data.

3. Research context and method

3.1. *The oil and gas industry in Southern Norway and the oil price shock*

The Norwegian O&G industry emerged in the 1960s, triggered by the discovery of the Groningen gas field in 1959 (Sæther, Isaksen, and Karlsen 2011). Even though Norway had no prior knowledge regarding oil and gas, it did have experience with other resource-based industries, such as energy (Wicken 2007) and aluminium (Sæther, Isaksen, and Karlsen 2011). Drawing upon its experience in these industries, Norway created an institutional framework to secure national ownership and control over all future discoveries of O&G. In 1969, a large offshore oil reservoir was discovered, which further accelerated the growth of this industry and made Norway a major oil producer. The O&G industry today is a diverse sector of upstream, midstream, and downstream activities including firms that deal with the exploration and production of oil and gas, transportation and storage, and process activities to turn raw materials into consumable products.

The region of Agder is situated on the southern tip of Norway and has a strong maritime tradition and a well-developed manufacturing industry (Isaksen 2018). Spurred by this industrial legacy, a local pioneering entrepreneur established one of the first oil-related firms in 1972. The firm constructed derricks and high-power hydraulic cranes for oil rigs. In the subsequent years, the firm strengthened its position as a quality provider of hydraulic cranes and won several large contracts. This attracted additional O&G related firms to the region, and Agder gradually became a significant hub for upstream O&G equipment and services.

In 2005, a cluster initiative for O&G firms called NODE, was formed in Agder. The aim of the initiative was to support and strengthen the position of regional O&G firms within the global value chain. Over the following years, NODE developed into a well-functioning cluster, hosting some of the world's most important O&G firms. In 2014, Innovation Norway acknowledged the central role of NODE and awarded the initiative the Global Centre of Expertise (GCE) status. At that time, the initiative consisted of 66 members who employed more than 10,000 workers comprising around 90 percent of the global market for drilling equipment (Hauge, Stouman, and Flatnes et al. 2019).

However, in 2014 the world experienced a major oil price shock. Within 18 months, the price of Brent Crude Oil¹ fell from 115.19 USD per barrel (noted on 19 June 2014) to 27.88 USD per barrel (noted on 20 January 2016), and remained at a low level for several years. According to Baumeister and Kilian (2016), this oil price shock had two underlying causes, namely an unexpected decrease in oil demand resulting from a slowing global economy, and an unexpected increase in oil supply resulting from growing shale-oil production in North America. This oil price shock had a major impact on the O&G industry in Agder, which will be analysed in the next section.

3.2. *Method and data collection*

The analysis draws upon in-depth and semi-standardised interviews with upstream O&G firms in Agder. The data collection was carried out in two rounds, specifically between October 2014 and July 2015, i.e. shortly before the oil price shock generated negative

¹Brent Crude is the type of oil that is extracted from the North Sea.

consequences for the firms, and between August 2018 and December 2018, i.e. when the industry was in full crisis. Both rounds included the same firms and the same interview questions, which allows for comparative analyses of innovation activities and knowledge networks both before and during the crisis.

The data collection conducted in 2014 encompasses all upstream O&G firms that were dedicated members of the NODE cluster initiative. Through the NODE membership registry, 39 firms were identified. This number includes all firms that deliver engineering products or services to the Norwegian O&G industry, while R&D organisations, educational organisations, and firms delivering indirect services, such as shipping, marketing, or consultancy, were excluded. 38 firms were interviewed in the first round, and only one declined our interview request. Thus, the interviews cover almost the full population (97,5%) of firms in the O&G industry in Agder.

The ambition for the data collection conducted in 2018 was to interview the same firms again. However, five firms were no longer available in 2018: Four had gone bankrupt, and one did not respond. Thus, from the 38 firms interviewed in the first round, 33 were interviewed again in the second round. In addition to the questions from the first round, the second round included an open question where the respondents were asked to reflect on how their firms performed during the previous four years. In most cases, the respondents provided a detailed reflection on their firms' development during the years of crisis.

The interviewees were top senior-level managers, most often the chief executive officers (CEO), and each interview lasted between 45 and 90 minutes. Among the interviewed CEOs, 24 took part in both interview rounds, which increased the comparability and validity of the two datasets.

A significant portion of the interviews was allocated to the collection of network data, following a roster-recall approach (Giuliani and Pietrobelli 2014). Here, each firm representative was provided a list (i.e. roster) of local firms and R&D organisations. They were asked to mark which actors, during the previous three years, their firm had a) monitored to be inspired for innovation, b) hired personnel from to strengthen innovation activity, and c) collaborated with in innovation projects. Finally, each firm representative was asked to complete the list with the names of additional knowledge-sourcing partners (i.e. recall). This procedure allowed us to map the complete knowledge network between O&G firms in Agder with their local and non-local partners.

As the empirical analysis is aimed at exploring the changes in innovation activities and knowledge networks over time, we chose to exclude firms that did not take part in both surveys. Thus, the final dataset consists of 33 firms. Because the dataset includes highly-sensitive company information, we chose to anonymise the firms, making it impossible to identify individual companies.

Table 1 presents key data on the interviewed firms. As the table shows, most firms experienced a dramatic drop in activity from 2014 to 2018. On average, the firms experienced a decrease in operating revenue by more than 75 percent.

Table 1. Key data from interviewed firms.

Firm (*)	Year 2014			Year 2018		
	Total Operating Revenue (Mill NOK)	Share of O&G- Related Revenue	Number of Employees	Total Operating Revenue (Mill NOK)	Share of O&G- Related Revenue	Number of Employees
x	47 642 (**)	100%	3507	5 511	100%	1631
x	8 677	99%	1735	1 881	90 %	746
x	2 534 (**)	100%	293	693	100%	155
x	2 367	100%	456	970	100%	350
x	1 667	95%	275	1 690 (****)	35%	411 (****)
x	1 033	80%	371	424	50%	204
x	920	100%	248	(****)	100%	(****)
x	640	60%	263	457	25%	240
x	480 (**)	100%	98	92	95%	20
x	433	100%	290	385	100%	215
x	398	100%	154	353	100%	130
x	380	80%	154	151	65%	83
x	358	20%	51	288	9%	53
x	342	40%	168	513	9%	258
x	285	30%	142	436	0%	130
x	260	100%	122	165	100%	87
x	215	96%	100	(****)	98%	(****)
x	206	90%	125	108	90%	77
x	176	33%	25	156	33%	42
x	170	100%	15	89	100%	26
x	98	100%	35	43	100%	16
x	91	95%	8	(***)	50%	(***)
x	90	98%	79	61	70%	32
x	74	30%	50	78	3%	39
x	67	65%	43	78	5%	47
x	54	95%	14	56	10%	20
x	52	55%	40	45	30%	37
x	43	95 %	37	43	18%	33
x	39	30%	29	(****)	0%	(****)
x	26	50%	15	520	5%	23
x	23	80%	8	13	80%	2
x	14	100%	7	11	100%	5
x	10	95%	6	3	95%	5
SUM	65 581	-	8 963	14 845	-	5117
Average	2 119	79%	272	512	60%	176

(*) Firm names are anonymised. (**) As this firm reported its revenue in USD, an exchange rate of 8.13 is used to offset exchange rate variations between 2014 and 2018. (***) Because this firm went bankrupt in 2019, the registry data for 2018 is not available. (****) Since these two firms merged in 2019, the registry data for 2018 is merged. (*****) Data not available. Source: Own data and data retrieved from Brønnøysund Register Centre.

4. Empirical analysis: innovation activities, networks and traces of new path development

4.1. Innovation activities

The need and capacity of firms to innovate differs between times of prosperity and crisis (Archibugi, Filippetti, and Frenz 2013). During periods of prosperity, firms have the financial capacity to invest into innovation. The perceived need to innovate is lower, however, due to high profits with existing products and services. During periods of crisis, this logic is reversed. Firms generate less profit, which decreases their financial capacity to innovate, while their need to innovate in order to adapt to changing situations is high.

In line with this, two-thirds of the interviewed firms stated that innovation was more important to them during the crisis in 2018 than it was during the successful period in 2014. For most of the firms, 2014 was a year of maximum demand, which was evidenced in expanded capacity and large backlogs. Rather than focusing on innovation of new products and processes, the firms centered their business activities on managing their day-to-day operations. This does not mean that the innovation did not take place. The interviewees stated that innovation was already important to them in 2014, but much more in 2018, when intense competition put pressure on the firms.

As shown in Table 2, the number of firms reporting innovation activity increased during the crisis. This growing focus on innovation occurred despite substantial decreases in revenue and severe redundancies.

Looking back on the situation in 2014, one of the larger firms explained how this was possible. At that time, the firm was at its peak performance and held ample innovation budgets dominated by expensive and long-time R&D projects. Yet, the R&D manager struggled to position innovation higher up on the corporate agenda, since the day-to-day business was intense, complex, and demanding of resource. When the crisis hit, the firm went through a significant organisational restructuring and the R&D department was shuttered. Thus, all future innovative activities had to be fully-financed from outside the organisation. During this period, the firm identified three innovation niches as particularly interesting to their customers, and where external financing was a possibility. These niches were projects that increased efficiency, reduced customers' operating costs, and focused on workplace health and safety. By targeting collaboration partners in these domains, the firm gradually built a portfolio of externally-financed innovation projects that addressed important areas in the O&G value chain. In that respect, the firm changed its innovation behaviour from closed to open and collaborative innovation, including external project partners and sources of funding.

The interviews showed that the crisis put transformative pressures on the firms. Rather than reducing their innovation efforts due to financial constraints, most firms increased their innovation efforts, but also changed the way in which innovation was organised. In the following section, we will analyse how the firms changed their knowledge sourcing networks in response to the crisis.

Table 2. Innovation activity in 2014 and 2018.

	Year 2014 (n = 33)	Year 2018 (n = 33)
Percentage of firms that have introduced product innovations in the last three years	75,8%	87,9%
Percentage of firms that have introduced new-to-the-market innovations in the last three years	63,6%	69,7%
Percentage of firms that have introduced new or significantly improved production processes, components, or materials in the last three years	63,6%	54,5%
Percentage of firms that have introduced a new or significantly improved business strategy in the last three years	69,7%	78,8%
Percentage of firms that have introduced new or significantly improved organisational structure in the last three years	57,6%	87,9%

Source: Own data

4.2. Knowledge sourcing and innovation networks

To analyse changes in innovation and knowledge networks, we distinguish between three common mechanisms which firms employ to source new knowledge for innovation, namely monitoring, mobility, and collaboration (Martin and Rypestøl 2018; Martin and Moodysson 2013). In line with that, the firm representatives were asked to identify all organisations (a) with which their firm had been collaborating and exchanging knowledge related to innovation, (b) from which their firm had been recruiting highly skilled employees, and (c), their firm had been monitoring for innovation inspiration, over the previous three years.

Table 3 displays the number of knowledge sources and their spatial location. Even though the firms' financial assets dropped significantly during that period, no major decrease in the number of relations was observed between 2014 and 2018.

The knowledge-sourcing mechanisms collaboration and monitoring are frequently used, with region representing the most prominent geographical level. Firms collaborate intensively on the local level, both in times of prosperity and crisis. The region as a key locus for collaboration is common among engineering-based industries, where long-term and trust-based partnerships and experience-based innovation modes are essential (Jensen et al. 2007; Asheim, Coenen, and Vang 2007). Monitoring is a non-binding and relatively inexpensive activity, which can explain the high number of monitoring relations. It is typically carried out via digital platforms or during physical meetings at conferences, trade fairs, and exhibitions (Aslesen, Martin, and Sardo 2019). The prevalence of monitoring, even at the local level, indicates how important it is that firms remain aware of their local collaborators and competitors, who face similar innovation challenges.

Mobility is a less common knowledge sourcing mechanism. Economic difficulties typically require firms to cut costs, and many of the interviewed firms were forced to lay off personnel, which led to a significant decrease in the total number of employees. However, as Table 3 shows, the total number of mobility relations did not decrease. This indicates that many firms laid off and recruited at the same time, seeking new personnel with the necessary skills and competencies to overcome the crisis.

Table 3. Number of knowledge sourcing relations in 2014 and 2018.

Knowledge Sourcing Mechanism	Spatial Dimension					
		Regional	National	International	SUM	
Collaboration	2014 (n = 33)	219	25	8	2014 (n = 99)	252
	2018 (n = 33)	210	60	53	2018 (n = 99)	323
	P-value	0.8012	0.0332(**)	0.0085(***)	P-value	0,0952(*)
Mobility	2014 (n = 32)	58	14	0	2014 (n = 96)	72
	2018 (n = 32)	69	10	0	2018 (n = 96)	79
	P-value	06083	0.4740	-	P-value	0.7489
Monitoring	2014 (n = 32)	207	10	7	2014 (n = 96)	224
	2018 (n = 32)	191	19	23	2018 (n = 96)	233
	P-value	0.05964	0.0478(**)	0.1144	P-value	0.7773
SUM	2014 (n = 97)	484	49	15	2014 (n = 291)	548
	2018 (n = 97)	470	89	76	2018 (n = 291)	635
	P-value	0.7826	0.0264(**)	0.0023(***)	P-value	0.1288

A paired t-test was used to calculate the P-values. * Significant at a 10% level; ** Significant at a 5% level; *** Significant at a 1% level. Source: Own data

Although the region is still the main arena for knowledge sourcing, it is possible to see a shift towards more national and international knowledge sources. The number of extra-regional monitoring and collaboration sources increased significantly. Several interviewees noted this change and stated that the crisis had sparked a new international orientation based on the necessity to find new markets. This indicates that extra-regional knowledge sourcing is particularly vital during times of crisis, as it can contribute to revitalising existing knowledge bases and stimulate processes of new path development (Aslesen, Hydle, and Wallevik 2017; Trippl, Grillitsch, and Isaksen 2018).

Table 4 shows the dominating actors in the network, based on the network measure in-degree centrality. According to network theory, nodes with a high level of in-degree centrality have many ties connected to them, which can indicate their relative importance (Nelson 1989; Wasserman and Faust 1994). However, as social capital theory stipulates, weak ties can also be valuable sources of new knowledge and can contribute to overcoming lock-in (Grabher 1993; Granovetter 1973). Despite these conceptual ambiguities, in-degree centrality can be viewed as a suitable measure for identifying influential firms in the network.

As shown in Table 4, the four firms with a very central network position in the first interview round held their position. The most central firms are rig-equipment producers with a dominant role in the industry and high annual revenue. Thus, in this case, the regional anchor firms were also the most prominent knowledge-defusing firms regarding monitoring, mobility, and collaboration. The analysis indicates that most firms maintained their network position, which is to say that firms with central roles during times of prosperity held these same roles during the crisis.

Table 5 extracts R&D organisations from the list of knowledge-sourcing partners, thus showing the extent of knowledge sourcing from R&D organisations. As the literature can attest, radical innovation is often the result of science-based R&D or the combination of analytical knowledge and other types of knowledge bases (Grillitsch, Asheim, and Trippl 2018; Grillitsch, Martin, and Srholec 2017). Dedicated R&D organisations, such as universities and research institutes, play a unique role in innovation-based regional development (Benneworth, Pinheiro, and Karlsen 2017; Smith 2007).

Given the decline in firm-level resources, one would expect firms to reduce their engagement with R&D organisations. However, Table 5 indicates that O&G firms instead increased their knowledge-sourcing activities from R&D organisations significantly.² This underscores how important analytical knowledge is to innovation, in general. In situations where the transformative pressure is high, analytical knowledge is essential when it comes to innovation. Further, one can observe a change in the geography of knowledge sourcing from R&D organisations, in which the number of extra-regional knowledge sources increased between 2014 and 2018, which speaks to the growing necessity of extra-regional knowledge in times of crisis.

²The increase in collaboration and monitoring is statistically significant.

Table 4. In-degree centrality in 2014 and 2018.

Firm (*)	Year 2014				Year 2018			
	Collaboration	Mobility	Monitoring	SUM	Collaboration	Mobility	Monitoring	SUM
x	10	3	14	27	8	6	16	30
x	11	1	15	27	8	7	14	29
x	7	4	12	23	4	4	5	13
x	9	2	10	21	9	2	11	22
x	8	2	7	17	2	3	8	13
x	7	0	9	16	5	0	6	11
x	4	2	7	13	2	3	2	7
x	6	0	6	12	4	1	5	10
x	4	2	4	10	3	2	5	10
x	4	0	6	10	7	1	7	15
x	4	0	5	9	4	1	5	10
x	5	2	2	9	2	0	2	4
x	5	1	2	8	4	0	5	9
x	4	0	4	8	1	0	0	1
x	4	0	4	8	4	1	2	7
x	4	0	3	7	2	0	1	3
x	3	1	3	7	2	2	4	8
x	4	0	3	7	3	0	1	4
x	4	0	3	7	3	0	3	6
x	4	0	2	6	4	1	3	8
x	3	2	1	6	0	0	0	0
x	4	0	1	5	5	0	1	6
x	3	1	1	5	2	0	1	3
x	2	0	3	5	5	0	5	10
x	2	1	1	4	2	0	1	3
x	1	0	2	3	1	0	4	5
x	2	0	1	3	0	0	0	0
x	2	0	1	3	4	0	0	4
x	1	1	1	3	1	0	1	2
x	1	2	0	3	2	0	1	3
x	0	0	1	1	2	0	3	5
x	0	1	0	1	0	0	0	0
x	0	0	0	0	0	1	4	5
SUM	132	28	134	294	105	35	126	266

Numbers display in-degree centrality. (*) Firm names are anonymised. Source: Own data

4.3. Innovation strategies and traces of new path development

As demonstrated in the theory section, innovation and knowledge sourcing can steer regional development onto several different trajectories, known as forms of new path development. These forms differ in the degree of novelty of the paths as well as the underlying mechanisms (Asheim, Isaksen, and Trippl 2019). A path is in this context understood as the aggregated development of firms and related organisations in a specific field. Even though firms are not the only agents of change, the activities, decisions and strategies of individual firms are pivotal to the development of the aggregated path (Hassink, Isaksen, and Trippl 2019; Trippl et al. 2020).

During the 2018 interviews, the firm leaders were asked to reflect upon the progression of their firm between 2014 and 2018 and to describe how their business and innovation strategy has changed since the beginning of the crisis. Based on their answers, we grouped the firms according to whether their behaviour and innovation strategy corresponded to the mechanisms underlying path extension, path upgrading, path importation, related path diversification, unrelated path diversification, or path creation. The categorisation of the firm behaviour and innovation strategy is shown in Table 6.

Table 5. Number of R&D partners for innovation activity.

		Spatial dimension			SUM
		Regional	National	International	
Year 2014	Collaboration (n = 33)	18	7	1	26
	Mobility (n = 32)	14	11	0	25
	Monitoring (n = 32)	15	0	0	15
	SUM (n = 97)	47	18	1	66
Year 2018	Collaboration (n = 33)	28	11	1	40
	Mobility (n = 32)	18	10	0	28
	Monitoring (n = 32)	20	4	0	24
	SUM (n = 97)	66	25	1	92

One firm did not provide information on mobility and monitoring in 2018 and was excluded from the analysis. Source: Own data

The information on business and innovation strategies reveals that the crisis triggered a process of change in many of the O&G firms. Only six of the interviewed firms stated that they continued their business operations with little to no innovation efforts, indicating a process of path extension. Twenty-one firms reported a major change in their business operations, aimed at enhancing competitiveness in current markets, which indicates path upgrading. Six firms reported major changes in their operations and innovations utilising a recombination of existing assets, which allowed them to enter new markets, indicating a process of related path diversification.

Most firms in the study described business and innovation strategies that, on an aggregated level, point to path upgrading. They did not aim for radical innovation or a diversification into entirely new markets, but focused on innovation and collaborations within established business networks in order to make themselves more competitive in current markets. In doing this, they managed to build on existing competencies and knowledge of their industry. Several firms in this category stated that O&G is a cyclical industry that eventually recovers. In the meantime, they chose to focus their innovation activities on two issues, namely reducing internal costs and making production more cost-efficient, which leads to reducing their customers' operating costs, and winning new contracts. Many of the respondents mentioned that these two priorities conflicted with each other. On the one hand, the firms had to reduce costs, while on the other hand, it was essential that they maintained a critical mass of qualified personnel who could innovate production with new, improved, and more cost-efficient solutions.

The firms that showed signs of related diversification stated that they diversified into new industries and markets, which was necessary to their survival during the crisis. They moved into new domains based on recombining their existing assets, including knowledge, skills, machines, and raw materials, and collaborated with actors they had not worked with previously. Examples include firms that moved from producing offshore oil drilling equipment to producing drilling equipment for the construction industry, diversifying from offshore oil drilling to the offshore wind turbines, and moving from offshore oil drilling to onshore water drilling. These transformation processes require a new combination of skills and knowledge and entail moving into new markets. Most of the firms described the exploration of new markets as an exciting experience. For some, the need to find new domains required the CEO to travel internationally in order to identify new clients and business partners. However, entering and innovating for new



Table 6. Forms of path development and corresponding firm behaviour and innovation strategies.

Form of Path Development	Mechanism of New Path Development (see Asheim Isaksen Trippel 2019)	Corresponding Firm Behaviour and Innovation Strategy	Number of Firms
Path extension	Continuation of an existing path based on incremental innovation along well-established technological trajectories	Continuation of existing business operations with no or only incremental innovation	6
Path upgrading	Major change of an industrial path onto a new direction based on a) new technologies, organisational innovation, and new business models (renewal); b) enhancement of position within GPNs; c) niche development through the integration of symbolic knowledge	Major change of business operations to enhance competitiveness in existing markets (e.g. via new business models, change in GPN position, or significant innovative niche development)	21
Path importation	Setting up of an established industry which is new to the region and unrelated to existing industries in the region	Relocation of business operations to other regions	0
Related path diversification	Diversification into a new related industry for the region building on competencies and knowledge of existing industries (regional branching)	Major change in business operations and innovations from related asset combinations (knowledge and skills) that leads firms into new industrial branches; knowledge exchange with actors in the same regional industry	6
Unrelated path diversification	Diversification into a new industry based on unrelated knowledge combinations	Major change in business operations and innovations from unrelated asset combinations (knowledge and skills) that leads firms into new industrial branches; knowledge exchange with actors in dissimilar industries and regions.	0
Path creation	Emergence and growth of an entirely new industry based on radically new technologies and scientific discoveries or as an outcome of new business models	Fully overturned business operations as a result of radically new technologies or business models	0

Source: Own draft

markets is not an easy task, and several of the firms were surprised by their success. As one firm representative said: *'If you, back in 2014, told me that we would sell for 45 million NOK to alternative markets in 2018, I would simply not have believed you'*.

Diverging from existing paths of development can be challenging and is not realisable for all firms. During times of crisis, path extension can be a reasonable or necessary strategy. For example, one firm centred its entire business on a single product innovation. The innovation was introduced in 2004, and since then, the firm has amassed large revenues. When the crisis hit, the firm had no option but to downscale its production and wait for things to improve. Thus, some firms have no better alternative than to wait for a recovery of the existing market. Other firms asserted that even if alternative markets were available, they were not deemed profitable enough to enter.

Finally, as mentioned earlier, four of the 38 firms from the first interview round went bankrupt during the crisis, representing a process of path exhaustion. Even though it was not possible to interview these firms about why they failed, it is reasonable to argue that the crises caused, or at least accelerated, their decline.

5. Conclusions: implications for research and policy

In this paper, we investigated how the O&G industry in Agder responded to an exogenous shock, which moved a prosperous regional industrial growth path into a crisis. We apply a RIS perspective, which understands firms as connected by various types of knowledge interdependencies, and link to the debates on new regional industrial path development and regional resilience (Hassink, Isaksen, and Trippel 2019; Martin and Sunley 2015). Empirically, we observe changes in the firms' innovation behaviour and in their innovation networks, and we identify different traces of new path development.

The analysis demonstrated that all firms in the Agder O&G industry were affected by the oil price shock and experienced a significant decrease in operating revenue. The drop of the oil price constituted a major shock to a flourishing industry and caused a crisis that lasted for years. Despite the new and harsh economic situation, the majority of firms did not reduce their innovation efforts. Instead, they chose to increase their innovation activities in order to adapt to their new circumstances.

Regarding the firms' innovation networks, we found no major change in the network structure or centrality of key actors, but observed two issues: First, a change in geography, namely a shift towards more national and international knowledge sourcing during the crisis. Rather than relying on the local skills and established collaboration partners, many firms reached out to new and extra-regional sources of ideas. This speaks to the key role played by extra-regional knowledge sourcing as a facilitator for regional industrial transformation and renewal (Aslesen, Hydle, and Wallevik 2017). Second, many firms intensified their interactions with RIS support organisations, in particular with public R&D organisations that provided science-based skills and analytical knowledge. This attests to the important role of RIS support in times of crisis. When firm-internal assets become scarce, firms can draw on system-wide assets, especially if they locate in RISs that are rich in such assets (Isaksen, Langemyr Eriksen, and Rypestøl 2020). The literature on regional resilience reinforces this argument, maintaining that highly innovative regions and regions with a strong university-presence are less vulnerable to shocks and recover faster from economic crises (Bristow and Healy 2018; Simmie and Martin 2010).

Concerning innovation strategies, we find that firms employed different approaches to cope with the crisis, which can be linked to different forms of new regional industrial path development. Many firms increased their innovation efforts with the aim of cutting costs and becoming more efficient in existing markets. New knowledge was sourced mostly from known business partners and from established networks. This innovation strategy is not likely to cause the emergence of entirely new industries, but can be a sign of path upgrading, building upon existing competencies and knowledge. A smaller group of firms was rather far-reaching in their renewal efforts. They innovated in an attempt to enter new markets, and engaged in knowledge sourcing and collaboration with new, often extra-regional firms, or with local R&D organisations. This innovation strategy has the potential to trigger related path diversification in the region, meaning diversifying into new industries based on related knowledge combinations. Another small group of firms did not make any noticeable innovation efforts and continued their business operations as before. The reasons for such an attitude can be manifold, including a lack of perceived need to innovate or a lack of capacity to adapt to the new situation.

These findings have implications for research on new path development, but also for policy that attempts to facilitate regional industrial renewal and change.

First, the question of how firms, industries, and regions respond to exogenous shocks is of high academic relevance. The literature on resilience provides a fertile ground for understanding the effects of shocks on regional economies and clusters (Martin and Sunley 2015, 2020; Henry, Angus, and Jenkins 2021), and can well be linked to the notion of regional industrial path development. New path development is typically studied with a focus on knowledge creation and recombination, accounting for multiple actors and agency, institutional layers and geographical scales and how these interact when industries emerge and transform (Hassink, Isaksen, and Trippel 2019; MacKinnon et al. 2019). The events that create transformative pressures often remain unexplored in this literature, and so do the consequences that various exogenous shocks can have on different regional development paths. Future research should put additional emphasis on the different types of shocks and crises, including economic, political, health, or environmental ones, as well as the factors that make some regional development paths more resilient than others.

Second, the study has implications for policy that aims to support regional economic resilience and adaptability. The quality of the RIS and its support structure can be seen as pivotal to safeguarding firm survival in times of crisis. Regions that provide a strong and diversified institutional and organisational support structure, and a strong analytical knowledge base, are more likely to adapt to and recover from crises (see also: Bristow and Healy 2018; Giannakis and Bruggeman 2017). Furthermore, we find that many firms seek to explore new markets and find new collaboration partners, often in other regions or countries. Thus, policies that facilitate collaborating and knowledge exchange transcending regional and national borders are more likely to be successful in times of crisis than policies that merely focus on intra-regional collaboration (MacKinnon et al. 2019). Consequently, we should regard the strengthening of RIS support functions and the improvement of national and global connectivity as principal elements for policies aiming at regional economic resilience and industrial renewal.

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ORCID

Jan Ole Rypestøl  <http://orcid.org/0000-0002-1855-2060>

Roman Martin  <http://orcid.org/0000-0001-5003-0986>

Nina Kyllingstad  <http://orcid.org/0000-0001-8563-2119>

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