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Regulation under uncertainty: The coevolution of industry and regulation

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Abstract

As production and design disintegrate and become more collaborative, involving dynamic relations between customers and firms supplying complex subsystems and service, products and production methods become more innovative but also more hazardous. The inadvertent co-production of latent hazards by independent firms is forcing firms and regulators to address the problem of uncertainty – the inability to anticipate, much less assign a probability to future states of the world – more directly than before. Under uncertainty, neither the regulator nor the regulated firms know what needs to be done. The regulator must induce firms to systematically canvas their practices and identify potential hazards. But recognizing the fallibility of all such efforts, the regulator must further foster the institutionalization of incident or event reporting procedures: systems to register failures in products or production processes that could be precursors to catastrophe; to trace out and correct their root causes; to alert others in similar situations to the potential hazard; and to make certain that countermeasures to ensure the safety of current operations are taken and the design requirements for the next generation of the implicated components or installations are updated accordingly. In this essay we develop these arguments and look closely at changes in the Norwegian offshore oil and gas industry and its regulator, the Petroleum Safety Authority to better understand the coevolution of vertically disintegrated industry and new forms of regulation.

Keywords: incident reporting, meta-regulation, Norway, oil and gas industry, uncertainty.

1. Introduction

As production and design disintegrate and become more collaborative, involving dynamic relations between customers and firms supplying complex subsystems and service, products and production methods become more innovative but also more hazardous. Independent suppliers learn rapidly from pooled experience with a wide range of customers; close cooperation between these competent suppliers and final producers generates further innovation through interactive improvement in the designs of each (Gilson *et al*. 2009; Herrigel 2010 Ch 5–7).

Creative collaboration of this kind, however, also introduces hidden hazards. To take recent examples: defective airbags supplied by a leading manufacturer to a number of auto companies exploded over a period of years, most frequently in humid environments, with lethal results. Early versions of an innovative air bag supplied to General Motors functioned as intended, but interacted in unexpected ways, again over a period of years, with faulty ignition switches, so that the airbags were deactivated just as crashes occurred (Energy and Commerce Committee 2014; Valukas 2014; National Highway Traffic Safety Administration [NHTSA] 2014a,b). Pathogens periodically enter global food supply chains and then propagate widely as adulterated foodstuffs are incorporated into diverse batches and the processing equipment becomes contaminated (United States Department of Agriculture 1996, 1998; Federal Food Safety Working Group 2011). Communication breakdowns between energy companies, drilling rig contractors, and oil field services suppliers

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have been implicated in offshore catastrophes, such as the explosion and sinking of the Deepwater Horizon platform (Chief Counsel's Report 2011; Deepwater Horizon Study Group 2011; National Commission 2011; Norwegian Oil Industry Association 2012). The Boeing 787 Dreamliner fleet was grounded in its first service year by problems originating in a faulty lithium-ion battery supplied by a Japanese manufacturer (Levin 2014; NHTSA 2014a,b; NTSB 2013a,b).

The inadvertent co-production of latent hazards by independent firms is forcing firms and regulators to address the problem of Knightian uncertainty – the inability to anticipate, much less assign a probability to future states of the world – more directly than before (Knight 1921). Traditionally, regulation assumed that firms knew the risks they faced and the costs of mitigation, but the public regulator did not. Firms had strategic incentives to use this information asymmetry problem to frustrate costly supervision. The regulator's task was to elicit from firms the information necessary to establish public-regarding but economically feasible standards and rules, while avoiding "capture" or ceding regulatory control to its addressee.

Under uncertainty, however, neither the regulator nor the regulated firms know what needs to be done. The initial regulatory problem is to supervise firms' investigation of risks that have been identified and ensure that effective mitigation measures are in place. Typically, the regulator requires firms to present plans specifying the risks of proposed operations, how those risks will be mitigated, the tests by which the mitigation's effectiveness will be verified, and the methods for recording test results. But recognizing the fallibility of all such efforts, the second regulatory task is to foster the institutionalization of incident or event reporting procedures: systems to register failures in products or production processes that could be precursors to catastrophe; to trace out and correct their root causes; to alert others in similar situations to the potential hazard; and to make certain that countermeasures to ensure the safety of current operations are taken and the design requirements for the next generation of the implicated components or installations are updated accordingly.

We will call such systems of regulation under uncertainty recursive, or, drawing on American Pragmatism, experimentalist, because they continuously revise initial and inevitably incomplete understandings of hazards in light of shortcomings revealed by the efforts to address them (Sabel & Zeitlin 2008; Sabel & Simon 2011). From yet another perspective, thinking of the regulator's role in inducing ground level actors to formulate and update detailed plans for risk identification and mitigation that no central rulemaker could possibly hope to approximate, we can regard oversight authorities of this type as a meta-regulators (Coglianese & Mendelson 2010; Gilad 2010).

In this essay, we look at the coordinate changes in the organization of industry and regulation that make it both imperative and possible to supplement the familiar, pre-market access, or ex ante review of product and production process quality and safety with post-authorization or ex poste monitoring of potentially hazardous incidents. To show how these general tendencies can play out in practice we look at developments in the offshore oil and gas industry on the Norwegian Continental Shelf (NCS) and its regulator, the Petroleum Safety Authority (PSA). The Norwegian industry was built on hierarchical foundations, and these origins make recent moves toward vertical disintegration and new forms of collaboration by new configurations of industrial and regulatory actors especially salient.

By the standards of popular and academic discussion, the PSA is a model agency (Lindoe *et al.* 2012; Bennear 2015). It has neither been captured by incumbent firms to the detriment of the interests of potential entrants, nor has it been influenced by the deregulatory enthusiasms of the last decades, nor paralyzed by bureaucratic procedure. While the PSA monitors operators closely, and alerts them to possible lapses in managerial control, it strictly refrains from proposing or endorsing solutions, lest it create safe harbors that discourage innovation. Operators alone bear the ultimate responsibility for meeting regulatory requirements. The PSA's independence and rulemaking flexibility are buttressed by the participation of strong oil industry unions in a tripartite system of problem solving. Norwegian discussion attributes a large part of the PSA's success to this "Nordic" or "Norwegian" model (Engen 2009).

Yet operations on the NCS are more catastrophe-prone than the widespread admiration of the PSA and its collaboration with industry would suggest. In May 2010, almost exactly a month after Deepwater Horizon exploded as gas rose to the platform during well cementing, there was a similar gas influx at well C-06 in the Norwegian Gullfaks field. But for a favorable wind, the outcome would have been catastrophic (Statoil 2010). The information management failures that caused this near miss were strikingly similar to those of another potentially disastrous incident at the Snorre A platform in November 2004 (Brattbakk *et al.* 2004). To judge by this outcome, independence and flexibility are necessary but not sufficient conditions for regulatory success under current conditions. Indeed, there are some indications that shared assumptions inherent in the tripartite, Norwegian model – for example, the now discredited view that improving workplace safety and reducing industrial accidents also reduces the risks of catastrophic failure – long blinded

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the actors to new threats. It appears that they were jointly subject, although perhaps in varying degrees, to what has been called "cultural" capture, with the irony that the culture was of their own making (Kwak 2014).

Over the last decade, both the PSA and the industry have responded to the near misses and the apparent failure of the Norwegian model to learn by laying the foundations of an incipient incident reporting system that covers the entire cycle of production from drilling a well to plugging and abandoning it (Engen *et al.* 2013). The shift toward more continuous performance monitoring is also reflected in the emergence of successful new drilling consortia, in which innovative operating companies and independent suppliers improved their productivity and accident records by systematically pooling experience and adjusting drilling and safety plans accordingly. These changes in the Norwegian oil and gas industry are part of a general trend in the sector. A recent final rule on Blowout Prevention and Well Control of the Bureau of Safety and Environmental Enforcement – the oversight authority for the safety of US offshore drilling, organized in the aftermath of Deepwater Horizon – mandates, for example, a rigorous incident reporting system for the most crucial equipment and closer real-time monitoring of offshore operations.[1]

A close look at Norwegian developments thus helps us better understand how uncertainty prompts more rigorous collaboration among firms, and between the firms and the regulator, while highlighting the political and organizational difficulties that might obstruct such collaboration.

The remainder of this paper is in six parts. The next part presents some examples of the proliferation of incident reporting systems to give a sense of the range and speed of the development. Part 3 reviews the literature on regulation and on the hazards associated with complex, highly interdependent production, underscoring the mutual inattention to the information pooling and learning practices increasingly central to production and regulation. Part 4 surveys the development of the oil and gas industry on the NCS and the key features of the current regulatory regime. Part 5 details the regime's increasingly salient costs while Part 6 looks to signs of renewal in the emergence of new consortia that outperform incumbents, and in the emergence, under the auspices of the Norwegian Oil and Gas Association (NOG), of incident reporting fora that cover the entire life-cycle of a well. Part 7 concludes by arguing that because of the range of stakeholders it engages and the range of information it produces, the new incident reporting system is likely to reduce the chances of regulatory capture, including "cultural" capture of the kind which seems to have partly inhibited the PSA's response – the new system's increased reliance on information provided by firms notwithstanding.

2. The profusion of incident reporting systems

The antecedents of the current incident reporting systems emerged in the closing decades of the last century. In United States (US) nuclear power safety, for example, plants had to meet demanding licensing requirements. Once in operation they were required to report all potentially dangerous operating events, ranging from unexpected equipment deterioration to power generation disruptions to the Nuclear Regulatory Commission (NRC). The NRC evaluates the reports and alerts all operators to the possibility of the same or analogous hazards. Responses to such notices are evaluated by frequent peer reviews (Government Accountability Office [GAO] 1991; Rees 1994, pp. 23–50; Morrow *et al.* 2014). Following the explosion in 1988 on the Piper Alpha platform – the worst offshore disaster to date, with a loss of 167 lives – and as part of a general shift away from uniform, prescriptive regulation, the British regulatory authorities require energy companies to submit and update an installation-specific "safety case" every five years detailing methods for controlling routine operational risks as well as those associated with changes in goals, methods, or dangerous failures (Inge 2007).

But such regulatory systems long seemed to be exceptional responses to distinct and manifestly hazardous technological constraints: complex, continuous process operations with interdependent subsystems that transmit disruptions rapidly, often in unforeseen and self re-enforcing ways, with potentially catastrophic results for human operators, bystanders, and the environment. What is novel in developments since the turn of the millennium is the growing realization by both firms and regulators that rapid innovation through collaborative production diffuses much more broadly the kinds of uncertainty formerly associated with a particular class of technology, and that incident reporting systems are the foundation of an effective response.

Here are some examples: the US Department of Agriculture organized pilot programs in the mid 1990s in which US slaughterhouses undertook a hazard analysis of the critical control points (HACCPs) at which pathogens could enter the production process, and proposed and tested methods of avoiding or mitigating those risks. Outbreaks of foodborne illness vectored by leafy greens (especially dangerous because likely to be eaten raw) led California wholesalers in 2006 to create a regime – contractual, but enforced by a state inspectorate – requiring growers to apply

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HACCP methods on their farms. The Food Safety Modernization Act of 2010 codified and extended this regime to many more products under the jurisdiction of the Food and Drug Administration (FDA). But slow adjustment by the federal inspectorate in slaughterhouses, and foot-dragging by firms has rendered implementation halting and at times ineffective (GAO 2013). Convergent developments in the European Union, again prompted by crisis (the outbreak of mad cow disease, among others), and again involving the interaction of administrative action, legislation, and private standards, led to the de facto introduction of HACCP requirements in the early 2000s (Sabel & Simon 2011; Humphrey 2012).

Beginning in 1997, in response to series of accidents, the Federal Aviation Agency (FAA) and the commercial US air carriers agreed on an Air Safety Action Program (ASAP). Under ASAP, airline employees report, with assurance of lenient treatment, deviations from standard operating procedures that may violate rules but are almost surely unobservable by either upper level management or the regulator. An event review committee, consisting of representatives of the carrier, the FAA, and the reporting employee's union, decide corrective action by consensus. In cases of deadlock, the FAA representative decides. Each carrier in the program has a continuing analysis and surveillance system (CASS): a team which combines the carrier's ASAP reports with internal audits and other sources to spot alarming anomalies in operations and prioritize remedies. The FAA uses ASAP and CASS reports to monitor the carrier's performance (Mills & Reiss 2014).

Between 2004 and 2007, serious incidents revealed that the FDA was unable to capture information on the adverse effects of drugs it had already approved for use, and lacked authority to respond to warnings from foreign counterparts. An authoritative review found that increased pressures and possibilities for innovation, combined with the inherent limits of controlled efficacy and safety tests – trial periods too short to detect long-term effect, exclusion of persons with comorbidities typical of the eventual patient population, and the impossibility of sampling ethnic or other minorities that might respond idiosyncratically –required improved techniques for predicting drug-related hazards and enhanced authority to operate a post-approval surveillance system (Stratton *et al.* 2007). The Food and Drug Administration Amendment Act, enacted in 2007, authorizes the FDA to require a drug producer to conduct a post-approval study or trial to evaluate the extent of known risks, to assess preliminary indications of serious risks, or to use available data to identify previously unknown risks. But despite substantial progress in meshing the units monitoring pre-approval and post-approval (U.S. FDA 2012a,b), there are conspicuous gaps in the reporting system and, as in food safety, worrisome delays in generalizing pilot project results into new institutional routines (Carpenter 2010, Ch 9; Chen & Yang 2013, pp. 193–213).

In auto safety, the Transportation Recall Enhancement, Accountability and Documentation (TREAD) Act, passed in 2000 in response to fatalities caused by interactions between a faulty car design and certain tires, lays the foundation for an incident reporting system by requiring manufacturers to notify the National Highway Safety Transportation Agency (NHTSA) of product defects as well as injuries or deaths involving their products. In 2014, a consent decree was made between NHTSA and General Motors in which the latter agrees to report monthly to the former on efforts to eliminate the faults in its internal error detection systems that delayed (for a decade) identification of the air bag/ignition switch interaction (NHTSA 2014a,b).

While this quickening drumbeat of regulatory innovation attests the pervasiveness of uncertainty in collaborative production, the difficulties in implementation reflect the contradictory incentives for both firms and administrative authorities facing the new circumstances. On the one hand, increasing uncertainty reduces information asymmetries, thus diminishing firms' strategic advantage over the regulator and increasing the returns to cooperative hazard identification. Firms, moreover, are linked not only by shared suppliers, but also by common interests in avoiding disasters that taint the reputation of all and in learning from others experiences before encountering problems in their own operations. Such circumstances also favor cooperative construction of risk identification and incident reporting systems (Gunningham *et al.* 2004).

But on the other hand, faced with the practicalities of collaboration, large and capable companies may think it more prudent to build such systems internally and extend them to key suppliers by contract, rather than collaborate with less able partners, or reveal proprietary techniques to competitors. Less capable firms may resist exposing vulnerabilities to outsiders, and prefer to protest new regulatory requirements they may not be able to meet. Trade associations, representing firms along the whole continuum of capacity, will be pressured by some members to help organize incident reporting, but pressured by others to oppose new obligations (Finger & Gamper-Rabindran 2012; Gamper-Rabindran & Finger 2013).

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Similarly, some regulators, and their political constituents, may see cooperation with industry in incident reporting and related systems as an effective way to hold private actors accountable for responding to rapidly changing conditions. Others will view such cooperation as an abdication of public authority to the private sector (Steinzor 2011).

But although interests diverge, there appears to be directionality to developments. The rapidly increasing rigor of incident-reporting systems in industries such as oil and gas, where they have a long but fitful history; the abrupt centrality of such systems in industries such as food safety, where until recently they had a marginal role; and their increasing prominence in industries such as pharmaceuticals and vehicles in which they had an established but secondary role – all point to a tectonic shift in the nature of regulation, away from compliance as action in conformity with fixed rules and toward an obligation to collaborate in the identification and mitigation of emergent risk. Even half-measures in this direction tend to be self re-enforcing, as they reveal enough information to prompt further movement, although often only in the aftermath of further catastrophes.

Current writing on regulation and complex, hazardous systems in economics, sociology, and political science, as we will see next, has by and large ignored these developments, not least because of continuing preoccupation with well-established disciplinary concerns.

3. Regulatory breakdown or renewal? The limits of current debate about regulation

The literature on the relation between regulation and the avoidance of catastrophes arising from complex interdependence is, with a few, important exceptions, disjoint. The early economics literature focused on the problem of capture by incumbents; more recent work investigates market-based mechanisms for pricing in networks and other interconnected production systems. But that literature ignores the organizational hazards that interconnection creates. The debate in organizational sociology on complexity and catastrophe is dated: the pessimists see a tendency in modern technological development toward systems too complex to control; the optimists point to counterexamples of organizations that avoid catastrophe by inculcating a culture of vigilance. But neither side considers the kind of highly innovative, interconnected organization at issue today; nor do they address the role regulation does or might play in influencing outcomes.

Recent writing in political science takes a fresh look at the problem of capture. It questions the economists' initial (and often continuing) preoccupation with capture by incumbents, and finds that what seems like preferential treatment for established firms actually may be the rational and justifiable result of regulators' reliance on extended dealings with them, not the expression of political influence. This literature observes that the pharmaceutical industry, for one example, has shifted to co-production, making the industry more innovative, reducing the advantages of established firms, but also introducing hidden hazards. But the literature does not offer a theoretical account of the relationship between these developments. The result is a conceptual gap at the point of interest here: the intersection of the coordinate changes in industrial organization (disintegration/collaboration) and regulatory organization. This gap is only partially bridged by some thoughtful studies of regulatory innovation. We review these debates to highlight and clarify the assumptions of our approach in contrast with more familiar ones.

Economists in the US turned to the study of regulation in the 1960s and 1970s, as the sector-specific, New Deal agencies passed their apogee. The agencies' public charge was to ensure orderly and fair competition in the interest of both firms and consumers. The Interstate Commerce Commission regulated railroads, then trucking; the Civil Aviation Board oversaw commercial aviation; and the Federal Communications Commission, broadcasting and telephony. In fact, as Stigler (1975, 1988) and others documented, regulated firms used political influence to ensure that legislation or the administrative agency responsible for applying it favored incumbents, most effectively by restricting entrance to the industry. The returns to such protection were enormous to its few beneficiaries, while the costs were almost imperceptible to the countless consumers to whom they were ultimately charged. Capture became synonymous with incumbency protection.

As these sector-specific agencies were dismantled or reoriented beginning in the 1980s – in part a reaction against capture, in part an early recognition of the disintegration of industry that later gave rise to cooperative production – the focus of regulation shifted to economy-wide problems: pollution; the use of hazardous materials; product safety; and consumer protection in general. Capture became more difficult because it required cross-industry alliances, but also less rewarding because the new rules applied to all engaging in certain kinds of conduct, without distinguishing between

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insiders and outsiders. Instead of seeking preferential treatment, regulated entities sought a general relaxation or evisceration of the rules: deregulation (Posner 2013).

Economics, too, shifted focus in the 1980s and 1990s, from treating regulation as a special topic in political economy – the sale and purchase of influence – to reconceptualizing it as an instance of a broader class of principal–agent problems: to create incentives for the execution of her plans, the principal must first induce her agents – those who will actually carry out the work – to reveal private information about the costs to them of alternative actions. Without such information, it is impossible to fix efficient rewards. From this perspective, regulation was less concerned with institutionalized oversight and more with market mechanisms, such as contracts and auctions for eliciting the information necessary for effective decisionmaking (Laffont 1994). Thus, when confronted with catastrophes such as the Macondo blowout or the financial crisis, economists working from this vantage point are inclined to propose liability rules that ideally give private actors the incentives to seek the optimal level of precaution (Bennear 2012; Viscusi & Zeckhauser 2012).[2] But as noted above, Norway, for one example, already has liability rules of the intended kind, without achieving the expected results; the monitoring regimes that it and other countries are constructing in response to the limitations of these liability rules are nearly invisible from the economists' principal–agent perspective.

Nor does organizational sociology light the path of current developments. That discussion has been under the sway of debate between Perrow (1984) and other partisans of "normal accident" theory (NAT) and partisans of "high reliability" organizations (HRO) since the late 1980s. As the name suggests, NAT takes catastrophes to be inevitable, not aberrant (Perrow 1984; Beck 1992). They result from the rapid and unforeseeable propagation of disruption through interacting subsystems typified by the reactor core meltdown at Three Mile Island. Efforts to mitigate the risks by introducing alarms, fail-safe mechanisms, or back-up systems backfire because they introduce more complexity. And, in any case, the trend is toward larger-scale, more interdependent and, hence, more catastrophe-prone production. HRO theory responds by pointing to the extremely low accident rates in air traffic control and aircraft carrier launches and recoveries (in peacetime) to demonstrate that sophisticated technologies can be operated safely (Roberts 1990; LaPorte & Consolini 1991). Safety, the argument continues, depends on operators (inculcated to be) preoccupied with the possibility of failure, attentive to "weak signals" of disruption and, when appropriate, willing to rely on experience in disregard of bureaucratic rules (Weick & Roberts 1993; Weick & Sutcliffe 2011).

In retrospect, the two arguments talk past each other, and neither anticipates the current constellation of co-produced uncertainty and responses to it. HRO does not join issue with NAT because the sophisticated technological systems it considers are not highly interdependent or tightly coupled, as in nuclear power generation. Air space is divided into loosely coupled sectors and aircraft are carefully separated at takeoff, in flight, and on landing in both civilian and carrier operations. Thus, deviations in a sector or flight can be accommodated without causing a cascade of disruption in adjacent operations (Leveson *et al.* 2011). Moreover, neither the nuclear power plants at the heart of NAT nor the air traffic control systems that inform HRO are subject to the constant, joint innovation that creates uncertainty in the economy today. There are very few reactor types in service in the US, and almost all were built before 1974; the technology of launching and recovering carrier aircraft is likewise extremely stable, and operating personnel have "nearly full knowledge" of it (LaPorte & Consolini 1991, pp. 19–48, esp 29–30; Leveson *et al.*, p. 238).

Of course it is possible that NAT is right about the inevitability of catastrophe, and innovation just makes a dire situation worse. And if NAT is not right, it is possible that HRO's argument about a culture of vigilance or safety explains successful operations. But the evidence weighs against both possibilities.

Although NAT predicts that both complexity and risk will grow with time, if only through misguided efforts to reduce risk, nuclear power generation – the prototypical instance for the theory – has proved remarkably safe. Russian nuclear power operations are "vastly" safer than at the time of the Chernobyl reactor meltdown, largely because of collaboration between Russian operators and their foreign counterparts, under the auspices of the World Nuclear Operators Association (World Nuclear Association 2014b). The reactor meltdowns at Fukushima resulted from failure to design against an exogenous event – a tsunami – not the inherent complexity of the installation (World Nuclear Association 2014a). Moreover, as Norwegian experience shows, there are dramatic and persistent differences in management's capacity to control precursors to catastrophe. In sum, complex technological systems can be operated safely, provided that their operation is organized to be safe.

We will see, furthermore, that there is much circumstantial evidence for the view that safe operations are not a matter of a stand-alone culture. Rather, there is an interplay between the creation of institutions for detecting and correcting the underlying causes of abnormal events – routines for interrupting and eventually modifying routines –

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and the attitude and disposition development needed for a safety culture: incident reporting systems and the investigations they trigger foster vigilance, and vigilance underwrites reporting regime practices, thereby inducing the continuous scrutiny and revision of organizational regimes characteristic of experimentalist or recursive institutions (Kringen 2008).

The recent political science literature convincingly challenges the persistent view that regulatory policy is in effect sold to the highest incumbent bidder. Studies by Carpenter (2010), Gilad (2010) and Maor & Sulitzeanu-Kenan (2012) show that regulators often do attempt to vindicate public values, or at least their good faith interpretation of them. To secure the institutional autonomy to do this they have to build credible reputations for protecting the public from harm within their jurisdiction. In building such reputations they must sometimes innovate, acting in advance of public opinion, and sometimes defend themselves against criticism for lax oversight. But how is the view of regulators building reputations for protecting the public to be reconciled with the finding, associated with Stigler (1975) and confirmed many times since his work, that incumbent firms often do receive preferential treatment from regulators? In a series of exhaustive studies of the FDA, Carpenter (2004, 2010) shows that in important cases, decisions – such as quicker approval of applications to market new drugs – that appear to result from a preference for insiders are in fact better explained as the result of a rational decisionmaking process. Through extended dealings with regulated firms, the FDA learns in a very general sense which are reliable counterparts; the features of good types – strong research and development capacities, good internal systems of quality control, expertise in regulatory submission – have also traditionally been features of incumbent firms. But it is the FDA's experience of the firm's capacities and intent, not the fact of incumbency, that accounts for the outcome (Carpenter 2004; Maor & Sulitzeanu-Kenan 2012; Maor *et al.* 2013).

The invaluable contribution of this literature is to clear a space for debate about current developments in regulation by diminishing the discussion-stopping power of invocation of incumbency capture as an inevitable outcome. But the focus on relatively short-term dealings between the regulator and regulated entities or the pubic draws attention away from the longer-term changes in the very nature of the regulatory problem of interest here. In his work on the pharmaceutical industry, for example, Carpenter (2010) observes that the traditional advantages of incumbency are disappearing: new, small firms are as likely as large incumbents to have applications for new drugs approved. Carpenter notes, moreover, that these changes are rooted in new forms of collaborative production that make the industry more innovative while increasing the chances that new drugs approved for sale will be found to have dangerous side effects that escaped ex ante review. But these developments are treated as a kind of changing background to the close study of decisionmaking, with no systematic place in the careful modeling of the process by which the FDA learns to rely or not on its firm interlocutors (cf.: Carpenter 2010, pp. 585–685).

Another recent approach, meta-regulation, is rooted in the study of regulation itself, rather than in the disciplinary concerns of economics and sociology (Coglianese & Mendelson 2010; Gilad 2010; Gunningham 2010). It anticipates key aspects of the recursive model under discussion here, especially the changed regulator role. Rather than presuming to write uniform rules based on scientific study and such information as industry can be incentivized to provide, the meta-regulator induces heterogeneous, ground-level actors to actively investigate the particular risks they face and determine how best to mitigate them. Forms of meta-regulation differ in the way they conceive the heterogeneity of the regulated actors, the weight they give uncertainty, and, correspondingly, in the allotted regulator supervisory responsibilities.

For management-based regulation, for example, simple technical and managerial idiosyncrasies render firms in many industries heterogeneous. If it is also impractical to observe the regulated conduct of heterogeneous firms directly and sanction non-compliance, regulators cannot write rules that apply effectively to all. Moreover, in such settings production idiosyncrasies often cause management itself to overlook cost-efficient possibilities for reducing harms. Given this double cognitive default by the regulator and the regulated entity, the management-based approach recommends a duty to plan harm reduction. The core idea, exemplified in the Massachusetts Toxics Use Reduction Act (TURA) of 1989, is that planning and execution are complements: obligated to prepare plans for reducing the use and production of toxics, firms will discover opportunities for affordable, perhaps profit maximizing improvement that the regulator could not have anticipated but management will have overlooked; the discoveries make the plans self-executing even without a formal requirement to act on them (Coglianese & Lazer 2003; Bennear 2012).

But absent an obligation to enact plans and report results, recursive regulatory system improvement occurs only if the planning exercise touches off a self-sustaining planning and correction cycle in individual firms. This is not the case. In a careful environmental performance study in Massachusetts and the 13 other states that adopted similar regulation,

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Bennear (2007) found that pollution prevention planning reduced toxic releases by 30 percent – but only for the six years following statute adoption. The planning obligation reveals unexpected opportunities for improvement but does not lead to recursion that makes improvement continuous.[3]

The responsive regulation model proposed by Ayres and Braithwaite (1992), in contrast, sees heterogeneity in the actor's disposition to comply or not with regulatory obligations. The focus, accordingly, is on the optimal allocation of regulatory attention to good and bad types. In the model, the rational regulator plays tit for tat with firms: cooperative firms that make good faith and successful efforts at risk reduction receive little attention, while uncooperative ones receive plenty. The cost of this optimization is that regulators and other firms cannot learn from the most successful cooperators' good practices (Ayres & Braithwaite 1992; Baldwin & Black 2008; Black & Baldwin 2012).

The recursive or experimentalist model differs from these in emphasizing the importance of uncertainty, and with it the need for collaborative investigation by firms of emergent joint risks and potential responses to them. A crucial task for the meta-regulator, therefore, is to help organize this investigation and continuous improvement both in the capacity to detect risks and to ensure that firms respond to warnings. Given the rich and continuous information flows about firm conduct and capacity such regimes produce, a meta-regulator responding effectively to uncertainty will also be well equipped to address heterogeneous firm-type and technical set-up problems, while the reverse is manifestly not the case.

Nothing is served by making too much of these differences: Think of the recursive model emerging generally and under study here in the Norwegian offshore oil and gas industry as a member of the meta-regulation family in which the meta-regulator, faced with uncertainty, has responsibility for supervising and, if need be, helping to organize both pooled risk reduction plan evaluation and an incident reporting system to avert immanent harms and update risk awareness and understanding.

But even assuming that these considerations are correct, and there is a tectonic change in the direction of such regulation, the conceptual discussion indicates only the general line of thrust; local outcomes depend on the particular context, as developments in Norway demonstrate.

4. The emergence of the current Norwegian system

Norway as a developmental state: From infant industry/Condeep to NORSOK. When oil was discovered on the NCS in the 1960s and 1970s, the Norwegian state actively sought to develop a domestic industry. At the time, a few giant multinationals dominated the global oil industry and virtually no oil exploration or production know-how existed in Norway itself. The state pursued a two-pronged strategy to build a national industry (Engen 2009).

First, it allocated concessions to foreign multinational corporations to maximize its own returns (through leases and taxation), and required producers to use Norwegian suppliers and materials for drilling platform construction and product transport to and from the wells. Second, the state created Statoil, gave it extremely valuable concessions, and enticed international technology suppliers into deals that transferred know-how and technology both to Statoil and to the key private suppliers, Aker and Kvearner.

The strategy yielded a distinctively Norwegian platform technology – Concrete Deep Water Structures or Condeeps – which were heavy, gravity stabilized drilling structures capable of withstanding the North Sea's great depths and turbulent seas. Their construction redeployed and further developed longstanding Norwegian know-how with concrete (developed in the hydroelectricity generation business) and marine engineering and shipbuilding.

By the mid 1980s, the Norwegian oil industry was profitable and Statoil and key Norwegian suppliers had become internationally competitive technology producers (Andersen 1998; Engen 2009). When the new Gullfaks field was opened early in the decade, for the first time virtually all of the operators (Statoil, Norsk Hydro, Saga) were Norwegian, as were all of the crucial suppliers. Within a little more than 20 years, the infant industry strategy had succeeded in creating a Norwegian oil industry.

Success was short-lived, however, as falling oil prices in the 1980s revealed high Norwegian costs (especially labor costs) and forced structural adjustment. The state abandoned the infant-industry strategy, and in 1993 established the Norsk Sokkels Konkurranseposisjon (NORSOK), a framework program for restructuring the industry that gave the oil companies and the main suppliers greater freedom to design contracts, pursue new technologies, and choose subsuppliers and drilling locations. Operators and suppliers were encouraged to act more cooperatively to lower costs

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and develop competitive technologies and standards. The overall goal was to reduce the cost level on the NCS by 50 percent (Engen 2009 passim; Engen 2013, esp p. 347).

The results were ambiguous. On the one hand, the industry abandoned the Condeep structures and moved into the production of more technologically sophisticated floating drilling platforms, production vessels, and sophisticated automated subsea technologies. But on the other hand, the new flexibility generated significant price competition, leading to concentration and mergers among Norwegian suppliers and operators: Aker and Kvearner merged in 2001, while NorskHydro acquired the much smaller Saga in 1999. Statoil was partially privatized in 2001. State ownership was further diluted as the company purchased the oil and gas assets of the largely private NorskHydro, but then slightly increased in the years following the merger in conformity with a law requiring two thirds public ownership.[4] These reorganizations allowed adjustment to the cost environment, but left in place elements of hierarchy within and among firms that impeded subsequent innovation (Stinchcombe & Heimer 1985, p. 32).[5]

The Norwegian regulatory system: the Petroleum Safety Authority, tripartism and the Norwegian Oil and Gas Association. The Norwegian offshore regulatory system consists of three disparate and imperfectly integrated complexes. The first, centered on the PSA, is a functional regulation system involving strict operator liability (called "internal control") and indirect safety system monitoring (known as "acknowledgement of compliance"). The second, centered on union–management relations, sets an agenda for addressing risks to personal safety through negotiation (at the national level), and solving safety-related issues informally, by drawing on professional and craft capacities (at the workplace). The third, inchoate, complex is centered on the NOG and emerged in part in response to the PSA's efforts to study industry-wide risks. It is laying the ground for an incident-reporting regime for the industry. The three systems are imperfectly integrated at best, in tension or at odds at worst, potentially increasing the vulnerability of all actors – the regulator, industry and the unions – to the strains imposed by the current need to restructure under harsh conditions.

In the early 1970s command-and-control regime, the regulator prescribed the design specifications for permissible equipment or installations. In the functional regime that has developed since then, and is codified in regulations from 2010, the regulator specifies only the general requirements that equipment must meet if it is to function safely in the intended use conditions. Typically, the regulator and private consultants provide greater elaboration and detail through guidelines or "cookbooks." Often the incorporation of domestic and international standards secretes even more detail into the guidelines.

The internal control doctrine, which establishes the operator's ultimate liability for damages caused, complements functional regulation. This means that even if a regulated entity complies with guideline specifications and standards, it must still, in theory, actively search for better alternatives to the indicated solutions; if it chooses an alternative, it must justify its choice to the authorities (Kaasen 2013).[6]

In addition, several statutes regarding workplace safety have been read together with the internal control doctrine to obligate regulated entities to institute safety management systems (Work Environment Act 1977 as amended 2005, Section 2a). Such systems establish company-specific safety norms and routines for ensuring that these norms are enacted. Increasingly, the PSA checks compliance by examining safety management system scope and reliability rather than by direct inspection. "Compliant" safety management systems, however, do not lessen operator liability for damages. The regulations insist that operators have an overriding, continuing duty to "see to it that everyone who carries out work on its behalf, whether directly or through employees, contractors or subcontractors, complies with requirements stipulated in the health, safety and environment legislation" (Bang & Thuestad 2013, p. 214).

In the same spirit, the PSA issues no official approval to operate or an operating permit. Instead, it issues an "acknowledgment of compliance" (AOC), which underscores both the provisional character of the permission to operate and the Agency's refusal to officially endorse any solution.

Entwined with this internal control and safety management complex is a second, tripartite regime of labor-management cooperation, established under state auspices. The Working Environment Act of 1977 gave employees the right to halt work upon detecting an immediate threat to health and well-being without incurring liability for the costs of the stoppage (Bang & Thuestad 2013, p. 210f). This led to extensive collaboration between safety managers and worker safety representatives to address pressing issues at the workplace level (Kringen 2008, pp. 61–71; pp. 80–97).

National level collaboration came in the following decades, and is now organized in two tripartite fora: the Safety Forum, set up in 2000, discusses matters bearing on health and safety, but not collective bargaining, with the regulator.

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The PSA regards it as a setting to develop the management and labor trust and mutual understanding that is the informal foundation for formal regulatory compliance (Bang & Thuestad 2013, p. 223; Kringen 2008, pp. 83–4). A year later, NOG formed Working Together for Safety (SfS), which reaches beyond unions and employer associations to include oil firm, drilling contractor, and supplier representatives. SfS operates through working groups, which identify the root causes of problems in particular areas (e.g. falling objects) and harmonize and attempt to diffuse best-practice responses (Bang & Thuestad 2013, p. 223; Kringen 2008, pp. 83–9).

The third complex, in which NOG plays an increasingly active part, arose in connection with the preparation and use of *Trends in Risk Level in The Petroleum Activity* (RNNP). The PSA has published this annual report since 2001 (PSA 2016b). RNNP uses the incidence of defined hazard and accident conditions, such as low-level hydrocarbon leaks, to track changes in personal injury levels and catastrophic failure risks in the industry as a whole. New indicators are introduced from time to time. In 2006, for instance, the PSA conducted a well integrity pilot survey among seven operators on the NCS, and found that 18 percent of the double barriers between production wells and their surrounding formation were impaired (PSA 2006). As a result, the RNNP now includes a well integrity traffic light rating – green for two functioning barriers, red if both are impaired, with yellow and orange situations in-between (Kostøl 2014). Such data alerts the PSA, industry and the public to alarming developments and may trigger further inquiry (Lauridsen *et al.* 2012). Collaboration in the RNNP prompted the NOG to undertake research projects of its own, and these have helped create shared understanding of investigation and information pooling which, as we will see in Part 6, underpin the emergence of an incident reporting system.

5. The limits of the current regime

The regulatory constellation organized in the PSA and the tripartite fora has, like the Condeep and NORSOK development regimes, served Norway well. However, hidden costs and limits are emerging and increasingly becoming barriers to further risk reduction and increased efficiency. In this section, we look first at these hidden costs in regulation, then in industry organization.[7]

Limits of self-limitation as a regulatory strategy. Regulation under uncertainty depends on collective learning, especially by firms: Only rapid learning from pooled experience makes it possible to recognize operational risks that can't be identified ex ante before they are manifest as disasters. But the PSA's traditional orientation, as we have indicated, has not focused on building a collaborative incident reporting system infrastructure for ongoing information exchange among firms about hazards and their mitigation. Rather, the agency engaged with the principal operators bilaterally. Moreover, the PSA has primarily emphasized ex ante risk reduction through elaborate modeling exercises and has done little to direct attention to the operational risks that emerge only after a project receives an AOC. Attention to ex post risk was further narrowed by the traditional misconception that reduction of personal injury risk lowers catastrophe risk. Finally, tripartite fora distracted from ex post risk by constantly foregrounding agenda issues with which trade union central headquarters are particularly comfortable. Together, these dispositions long taken for granted as inherent in or even constitutive of the Norwegian tripartite model of functional control, guided the search for problems and solutions to them. In this sense, it could be said that the unions, the industry, and the regulator came to be captured by a culture of their own making.

The focus on individual operators. The PSA monitors major operator performance with dedicated multifunctional teams that suggest, with increasing threat of penalties if need be, areas for (urgent) organizational improvements. The teams regularly review the operation and data produced by "their" firm's safety management system and conduct periodic on-site audits. Systematic problems attract sustained interest. For example, the corrective to preventive maintenance ratio in a firm or facility is a serviceable indicator of the organization's ability to keep operations under control: the higher the ratio, the more often intervention corrects a breakdown that thorough understanding of situation could have prevented. A firm with a troublingly high ratio will be asked to develop and implement a plan to redress the balance.

As the industry moved into the new century, these dialogues have increasingly proven ineffective for two closely related reasons. First, the focus on operators largely ignores the extensive contemporary collaboration between drilling

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contractors and specialized service providers. More and more, the operator only exercises a primarily supervisory function on both offshore platforms and onshore activities. Thus, close monitoring of operators can easily ignore the most important part of operations. Second, precisely because the operators depend on collaborations that they do not completely control, their ability to correct systematic problems within the PSA's typically tight time constraints is limited. Hence, problems are identified but not resolved, and systemic vulnerabilities accumulate.

These difficulties are reflected in overall assessments of health and safety (HSE) risk levels and trends in the industry. The 2016 RNNP report notes, for example, that the total number of defined hazard and accident conditions associated with major accident risks, having decreased dramatically in 2012 and remained at low levels in the following years, rose again in 2015 (PSA 2016b, p. 24). Similarly, hydrocarbon leaks increased again in 2015 (PSA 2016bb, pp. 24–26). And, while the backlog of preventive maintenance decreased, there was significant variation across facilities, as was also the case with hydrocarbon leaks. This suggests that best practices are diffusing unevenly. The overall tone of the 2016 RNNP report was chastened: "it is surprising that this negative trend [in various indicators] appears so widespread, given the industry's stated focus on improving HSE conditions" (PSA 2016b, p. 11). A flurry of very recent but potentially catastrophic platform fires and leaks can only have underscored this quiet sense of alarm (Johnsen 2016; Reuters 2016).

The limits of quantitative risk analysis. The PSA emphasizes the use of quantitative risk analysis (QRA) to reduce foreseeable risks. QRA is based on historical failure rate data: a particular part or component is known to fail with a certain frequency under certain conditions. The more such parts are used in an assembly or installation, the more likely the ensemble will fail. QRA, thus, simply extrapolates from the specific known part failure rates to estimate the failure likelihood of a structure that combines various part quantities in novel ways.

This analysis is subject to two important limits. First, there is the domain problem: failure rates are derived from experience under a range of conditions; if parts or equipment are used in settings outside the range, the historical evidence may be unreliable. Take a crude but effective illustration of the problem: there are 50,000 wells offshore in the Gulf of Mexico, but only 41 high temperature/high pressure wells of the Macondo type. Is the failure or blowout rate of high temperature/high pressure wells in the Gulf of Mexico closer to 1/50,000 or 1/41? How could we decide without recovering information about, for example, the nature of the formations drilled, which has not been included in the failure rate databases?

A second limit on this kind of risk analysis concerns the exclusion of "human factors," or, more generally, organizational breakdowns as a disruption source. QRAs assume that parts as designed and built have an inherent failure rate. But many dangerous outcomes –hydrocarbon leaks during valve maintenance, for example – are caused by (organizationally-induced) human misuse of equipment. Making the equipment more robust will not by itself mitigate the hazard risk. Realization of the relative importance of organizational as compared to technical sources of breakdown is central to the push within industry and the NOG to construct incident reporting systems which do make "human factors" conspicuous (Skogdalen & Vinnem 2012).

By insisting that firms applying for AOCs "demonstrate" that their projects do not exceed precisely defined risk levels, the PSA invites gaming of QRA models. It inadvertently gives undue weight to the historical knowledge used in ex ante planning-stage risk mitigation, as against learning in the ex post operating phase. Organizational factors are, thereby, subtly and unintentionally downplayed in catastrophe avoidance.

The confusion of increased personal safety with catastrophic risk reduction. The Work Environment Act was remarkably far-sighted, obligating employers not only to establish management systems for protecting (and continuously improving) workplace safety, but also obligating firms to afford employees opportunities to participate in organizing work and otherwise exercising their autonomy. Of the Act's manifold purposes, concern for safety has been most robustly institutionalized and absorbed in union and management cultures. Safety concern shades into the conviction that successful individual risk management induces or facilitates broader management changes – especially more rapid learning from error – that generally reduce risks of dangerous failures. Such convictions have subtly shaped the PSA 's regulatory priorities and focus.

But experience in the last two decades has consistently shown that heightened personal safety does not make operations catastrophe-proof. Practitioners and academics repeatedly stress that the two domains are only loosely

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connected, and that it is dangerous, therefore, to use personal safety (change) measures as proxies for trends in what is variously called process safety or asset or technical integrity. For example, the US Chemical Safety and Hazard Investigation Board's careful review of the causes of BP's Texas City refinery fire in 2005, which resulted in 15 deaths, finds that "a very low personal injury rate at Texas City gave BP a misleading indicator of process safety performance"(US Chemical Safety and Hazard Investigation Board (CSB) 2012, p. 19). The Baker Report on the same incident is equally emphatic in criticizing BP's use of use of injury rates to measure process safety (Baker 2007, p. xiv; cf Hopkins 2000).

The PSA is aware of all of this. The webpage introducing the 2013 RNNP says flatly that the RNNP process has led to "a recognition that traditional indicators, such as personal injury statistics, are of limited use in measuring major accident risk" (PSA 2013). But revising the Agency's priorities accordingly is difficult. Safety management, where safety is still mainly understood first as personal safety, is a well-established profession in Norway, especially in the offshore industry; the PSA is entwined with it through daily exchanges and personnel career paths that circulate from industry to regulator and back. Beyond these ties, the agency is perhaps subliminally inclined to associate personal and process safety because the link is highly valued by unions and thereby given prominence in tripartite institutions.

The rigidity of the tripartite model. As we have seen, the tripartite safety issue discussion is institutionalized in two fora: the Safety Forum, convened by the PSA; and SfS, convened by NOG. The limits of such bodies stem from the difficulties that trade unions in all advanced countries have had in connecting effective shop floor and enterprise-level labor-management cooperative problem solving to regional and national level coordination and leadership (Schmalz & Dörre 2013; Schulze-Cleven 2016). Peak level difficulties in adjusting to continuous organizational and technical change are deeply rooted, the failure to connect local problem solving with the national agenda is recurrent, and the reasons for the missed connections are ill understood. For present purposes, we note only that failure to solve this problem leaves the Norwegian unions, like their counterparts elsewhere, inclined to advocate familiar issues – in this case workplace safety. In the Norwegian oil industry, this is manifest in a long-running and occasionally acrimonious dispute about the particulars of safe and affordable lifeboat design for evacuating crews on endangered platforms, or about fire hose location and design. These disputes take on symbolic significance and raise familiar, politically-charged questions: Profits before people? These are fundamentally important matters and are rightfully central to tripartite discussions (Kringen 2008, pp. 94ff; pp. 267–284). But however they are resolved, their very centrality crucially influences broader regulatory agenda setting. They can, thus, re-enforce the misleading impression that making personal safety the highest priority is the best way to make personnel safe.

If the analysis so far is correct, it is only a slight exaggeration to call these limits to the PSA regime unforced errors or evidence of cultural capture; nothing in legislation, or the Agency's founding commitments, would have prevented, or would today prevent, a reinterpretation of the internal control doctrine focused on support for an incident reporting infrastructure, rather than close monitoring of key operators, or de-emphasis of QRA in favor of more careful firm-level safety management and incident reporting system review. We will return to the possibilities for reorientation.

Pressure on Statoil. While NORSOK successfully responded to the infant industry's problems, the regime created relatively closed and hierarchically ordered organization forms that now struggle to accommodate the flexibility within and among collaborating firms required for successful adjustment today.

The most authoritative documentation of blockages in the Norwegian industry's organization is by Petoro, a state-owned company that manages Norway's portfolio of petroleum and natural gas exploration and production licenses (Petoro 2014). Petoro's most recent findings reveal that the Norwegian industry, and especially Statoil, is not only falling behind foreign competitors, but is actually backsliding – failing to meet benchmarks set by its own past performance.

One measure of this decline is that 25 representative routine drilling operations take, on average, twice as long to carry out today as they did *in the same wells* roughly 20 years ago (Petoro 2014, Slide 17). In large measure because of this operational slowdown, the number of wells drilled per rig, per year has declined dramatically; therefore, drilling costs increase while recovering dwindling reserves becomes more drilling intensive. The same real productivity declines are captured in increases in engineering hours per well or per ton, and workers needed to extract a barrel of oil (cf: Osmundsen *et al.* 2010).

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Second, even as the industry is performing familiar tasks more slowly, new technology diffusion in the field is slowing. Norway fell from 10th in 2005 to 40th in 2013 in the international league table of oil industry technology adopters (Petoro 2014, Slide 18). This nosedive is especially puzzling because, as Petoro notes, NCS firms are "quick to try new technology" (Petoro 2014, Slide 18). It would be surprising if they were not, as Norwegian capital goods suppliers to the industry became leading global players in these years. Local customers must, at least initially, have encouraged new equipment development and given useful performance feedback. What then, accounts for NCS firms (especially Statoil's) broad reluctance to push initial, isolated enthusiasm for innovation into general deployment? What is the relation, if any, between the diffusion slowdown and the slowdown in the execution of familiar routines?

The Petoro presentation speaks only of "creeping inefficiency" caused by self-defeating perfectionism and inability to prioritize, leading to excessive complexity in operations. The report also refers to friction in customer-supplier relations, and hence "the need for operator-supplier cooperation models" that give suppliers "the opportunity to participate" in deploying new technologies (Petoro 2014, Slide 19).

A more specific conjecture – compatible with Petoro's explanations – connects the slowdown in routine task performance with the delay in new technology diffusion. Many new technologies make more continuous and precise drilling operation measurement and control possible. But the level of cooperation between those observing the data flow and those conducting the drilling operation determines whether the technology in use increases efficiency or actually decreases it. Consider instrumentation for measuring drilling tool vibration: when coordination between data monitors and tool operators is high, early signs of vibration increases touch off a rapid search for ways to avoid reaching levels that jeopardize the tool. When cooperation between data monitors and tool operators is low, the operators respond cautiously, protecting the tool by slowing drilling, perhaps below speeds that would have been acceptable in an earlier period, before vibrations were measured. In this case, fear of mistakes and the search for "perfect solutions" lead to the proliferation of prudent, but inefficient, rules of thumb. As the sources of potentially alarming information increase, so too do the number of rules, and with them the number of trip wires that slow production. As managers come to see this connection, investments in new technology decline and the slowdown in routine operations fuels a disinclination to adopt innovations broadly.

But regardless of the precise explanation, it is clear from the Petoro account, and concurrence from many industry actors, that high costs stem from coordination problems, and that the latter are exacerbated by two additional and widely remarked circumstances: the increasing shift of platform control to onshore units that lack the necessary contextual information to make good judgments; and decreasing head drill manager tenure on the rigs. What was once the apex of a career is now a stepping-stone to an offshore management position.

All of these pathologies and many related ones are noted in a widely read report by the IRIS Institute in Stavanger on the Gullfaks C near miss. The report, sponsored by PSA and based on extensive access to all players involved in the incident, underscores the organizational blockages pervasive in Statoil and calls attention to perverse interactions between the regulator and the firm, especially the failure of both the PSA and Statoil managers to establish routines that actually address the organizational problems that both identify as pressing (Austnes-Underhaug *et al.* 2012).

6. Signs of renewal

But the PSA, the NOG, and the rig operators and supplier firms on the NCS are hardly supine in the face of these developments. Regulatory initiatives and the emergence of innovative production consortia hint at the possibility of robust systematic learning in the service of both safety and efficiency on the NCS.[8]

On the regulation side, two important incident-reporting programs have emerged: the Hydrocarbon Leaks Project and the Drilling Managers Forum's Well Life Cycle Incident Reporting System. The history of both goes back to the turn of the millennium, but in both cases, developments have accelerated and become more institutionally salient.

The Hydrocarbon Leaks Project. Hydrocarbon leaks are a major precursor of accidents in the offshore oil and gas industry. In 1996, the NCS industry started registering leaks greater than 0.1 kg/second – the flow rate above which dangerous accumulations easily arise. The frequency of leaks was then increasing. It peaked in 2000, as the RNNP began publishing the indicator annually.

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The alarming trend led to two parallel projects between 2003 and 2008. NOG used accident reports in the gas leak reduction (GaLeRe) project to establish a rough classification of leak causes and suggest preventive measures (Røed *et al.* 2012). In the second project, the PSA traced the origins of many leaks to actions by improperly trained personal and introduced courses on manual operation with flanges, fittings, valves, and other equipment in response (Vinnem & Røed 2014, p. 88).

Although the frequency of leaks fell during the GaLeRe and PSA projects, it rose in the following years. In 2011, NOG, in cooperation with major NCS operators, organized a two-year, follow-on project to look more deeply into the root causes of leaks (Røed *et al.* 2012). The aim was to develop still more effective countermeasures by explicitly encouraging experience exchanges among NCS firms and between them and firms on the British continental shelf.

This study looked at the 33 leaks on the NCS from 2008 to 2012 for which company investigative reports were thorough and complete (Vinnem & Røed 2014, p. 95). The results confirmed earlier findings that equipment failure is a secondary cause of accidents (accounting for 20 percent of leaks), while the primary cause are manual interventions (accounting for 60 percent). The novelty of the report was to establish that failures resulting from manual interventions are usually caused by upstream errors in *preparing* the intervention: for example, a routine instruction that ignored lessons from earlier experience, or reference to a manufacturer's out-of-date drawing that did not correspond to the installed equipment. Fifty-nine percent of the faulty manual interventions resulted from such upstream failures, while only 27 percent were caused by errors introduced during work on the targeted equipment (Røed *et al.* 2012, p. 10; Vinnem & Røed 2014, p. 98). The study thus pointed to the need for continuous monitoring of (deviant) organization routines – an implication re-enforced by the finding that the divergence between the best and worst companies with respect to leaks has increased in recent years (Røed *et al.* 2012; Skogdalen & Vinnem 2012; Vinnem & Røed 2014; Bennear 2015).

The project touched off a cascade of promising institutional reactions. Several companies have compared their best maintenance practices, and the NOG, together with a working group including representatives from all active major NCS firms, has codified the project's results into a common best-practice guideline. The PSA refers to the project's material, giving it official weight. The project developed and introduced a standard questionnaire to address accident report inconsistencies and incompleteness, which draws attention to error incidence in various work process phases (Vinnem & Røed 2014).

Taken together, the Hydrocarbon Leak Project initiatives set the stage for improved reporting and more precise categories of analysis. And by making visible variation in individual firm performance, the project places even more pressure on laggard firms to adopt the project's version of industry best practices.

Drilling Managers Forum and well life cycle incident reporting. Roughly with the start of the new millennium, as the hydrocarbon leaks projects got underway, NOG began to develop, stepwise, and at least initially without any overarching design, industry-wide fora for the discussion, analysis, and response to well control incidents, such as sudden formation fluid influx into the wellbore – a "kick." Eventually, specialized groups were formed to track and deepen understanding of problems emerging in each well life cycle stage, from drilling to operation (well integrity), to plugging and abandoning. The groups are not yet a fully integrated system with common protocols for acquiring, analyzing, and disseminating information, but they are surely more than ad hoc initiatives, and they are depicted in NOG's own presentations as the foundation of a comprehensive structure.

The first and still central component of this emerging structure is the Drilling Managers Forum (DMF), established in 2002 under the leadership of Jan Krokeide, a respected drilling industry veteran, consultant, and NOG part-time employee. Drilling managers for 13 operating companies initially participated (Johansen 2002). The new forum emphasized that safety risks were best addressed by developing shared understanding of problems and responses. In addition to promoting improved HSE, the Forum keeps abreast of operational and technological developments; fosters experience exchange and learning; comments on proposed regulations; and assists in organizing and staffing further projects (Krohn 2011).

Three specialized fora –The Well Incident Task Force (WITF), the Well Integrity Forum (WIF) and the Plug and Abandonment Forum (PAF) – were developed out of the DMF to create an emergent well life cycle incident reporting system. The WITF convenes NCS operator and drilling contract managers to recommend ways to reduce well control event frequency and potential severity. The group analyzes recent well control incidents at monthly meetings and then

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posts elaborated versions of the cases (14 so far) on the web under the rubric of "sharing to be better" (NOG 2016a,b). The detailed cases typically include logs showing instrumentation readouts from critical moments during the incident, and are pedagogically structured with questions like: "Would you have reached this conclusion?" The incidents invariably highlight organizational factors: the data operator on a platform asks a geologist onshore to provide a calculation parameter; the geologist, distracted, tells the operator to consult a value table; the operator chooses the wrong value; and so on. The constant refrain is the need to question taken-for-granted routines, or, as one participant put it in a meeting we attended, "Assumptions are the mother of all screw ups."

The second forum in the new structure is the WIF. After the 2006 PSA study showing that nearly 20 percent of production wells were impaired, the WIF was formed to focus on the operating stage after the drilling unit hands the well to the production managers. The WIF produces guidelines on training, handover documentation, and standardized barrier drawings and comments on regulatory proposals (Krohn 2011). More recently, the PAF was created to protect the environment with a special focus on hazards created by novel configurations of wells drilled with new technologies (NOG 2015; Straume 2015).

The PSA is well aware of these fora and has made public gestures supporting them. For example, it refers to them in its revised 2013 NORSOK standards (PSA 2013)[9] and the fora figure prominently as promising new developments in the Agency's authoritative final 2014 report on lessons learned from the 2010 Deepwater Horizon accident in the US (PSA 2014).[10] Generally, the Agency has begun to emphasize the importance of uncertainty and, hence, the limits of ex ante risk identification. This naturally leads to an increasing emphasis on the improvement of risk management through ongoing monitoring of operations and incident reporting in collaboration with firms (Berg 2013; PSA 2015, 2016a). In setting its priorities for 2016 the PSA "will give particular emphasis to following up operational and organizational elements" in key areas of incident reporting, such as well integrity and control of hydrocarbon leaks (PSA 2016a, p. 19). And, in general, it will dedicate itself to being more attentive to "the uncertainty and knowledge dimension in risk assessments, the maintenance of safety critical equipment and the implementation of barrier management in the industry" (PSA 2016a, p. 19).[11]

Nonetheless, all of these promising developments are hampered by the fact that firms' engagement at every stage is voluntary. Despite its acknowledgement of the significant role that the new incident reporting fora play in coping with uncertainty, the PSA seems to be resistant to openly rethinking the scope of its own role in this emerging governance architecture, perhaps for fear of violating the hands off principles associated with the internal control doctrine. This increased emphasis on uncertainty and the incompleteness of the knowledge on which decisions are based is likely to be reinforced by a series of publications by Aven and others, which aim to examine these considerations in an enlarged conception of risk analysis (although these reflections, like those of the PSA itself, do not consider corresponding institutional changes) (Aven 2012, 2013; Aven 2014; Aven *et al.* 2014; Aven & Krohn 2014; Årstad & Aven 2017).[12]

The NOG is similarly hamstrung between the encouragement of the new structures and its traditional role as the agent of its members. Thus, although the NOG has substantial convening capacity, its power depends on the trust of its members. It cannot compel actions beyond those they authorize or willingly tolerate. While this tension is inherent in the nature of trade associations, in the Norwegian context it is expressed in two distinct ways.

The first concerns the extent of participation in incident reporting. Although individual managers are often quite open to professional exchanges and joint problem solving, the companies they work for often worry that incident information may damage their reputation, or reveal management system detail they consider proprietary. Therefore, not all companies allow their managers to participate in the fora, and those that do may not clarify until the last possible moment just how much information they are willing to make public through an incident discussion posting to "sharing to be better."

The second regards the protocols for collecting, analyzing, and diffusing incident information and results. Companies are not formally obligated to employ the new hydrocarbon leak questionnaire, nor to pursue the root cause investigation the questionnaire prompts, nor to respond in any way to incident reports. The "sharing to be better" cases invite such self-reflection, but stop there. Firms are left to their own devices to absorb the lessons learned or not.

These weaknesses in the emerging NOG constellation are cast in stark relief when contrasted with the systematic linkages in the analysis and information flows within the most sophisticated company-based incident reporting systems, such as Shell Oil's Learning from Incidents (LFI) process.[13] LFI both presupposes relevant stakeholder participation and has a bias toward organizational over simple manual or technological explanations of failure. Moreover, it complements its classification system for incident severity with a process for challenging classifications – an

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effective way of addressing the paradox that the eventual degree of severity may often be gauged only after an investigation triggered by a provisional estimate. "Causal investigation" aims to identify the organizational levels that ultimately "cause" the problem. For example, if a suspension wire on a crane breaks, the root cause might be located in a design problem, and the response might be to specify thicker wire for the intended purpose in the future. But the defect results also and more fundamentally from a failure in the organization of the design process, which overlooked the original misspecification. Finally, LFI analysis does not diffuse its findings through traditional reports. Rather, it uses a document presenting the circumstances contributing to an incident to prompt discussion among relevant parties: groups in facilities that could be implicated in similar incidents reflect, at each stage of the episode, on how *they* might have contributed to related problems, and what to do to avoid such contributions. The "observations inside conclusions" (OICs) produced by these groups often improve on solutions devised by the original incident investigation team.

The differences between the current NOG/DMF system and company best practice are important, but should not be exaggerated. The latest revision of the SfS guidelines for the Best Practice for Examination and Investigation of HSE incidents contains a thorough discussion of most cogent aspects of systems such as LFI, including a section on "alternative" learning forms that dovetails with the OIC's innovative and participatory features (Samarbeid for Sikkerhet 2014). This and much other anecdotal evidence suggests that the emergent NOG system is firmly connected to, and is not a backward variant of, the best company systems. The question, in other words, is not what the participants in the NOG fora know, but whether or not hurdles obstructing implementation can be overcome.

New forms of firm organization and contracting. One sign of organizational ferment and renewal in the NSC is the creation of some 60 new firms in different industry segments by managers from established companies, especially Statoil. Although their impact is hard to assess, key managers are plainly responding to incumbent producer rigidities. Their willingness to take substantial personal risks to realize plans that could not be put into action within the existing structures recalls the behavior of managers of US Steel and other American integrated producers in 1970s and 1980s, when they left their firms to establish what is today the highly competitive mini-mill segment in the steel industry (Herrigel 2010, pp. 100–138).

But the most conspicuous examples of contemporary NCS collaboration are new forms of drilling consortia that increase efficiency – to well above the area average – while reducing risk through rapid, joint learning. Traditional NCS consortia were makeshifts formed by smaller operators, none big enough to hire a rig alone. Typically, the largest of the cooperating firms hired a rig contractor and service providers under terms that were then accepted by the others. This arrangement allowed smaller firms to access rigs, but largely precluded efforts to learn from ongoing operations as the terms of cooperation were fixed once and for all at the outset.

Starting in the late 2000s, as rig contract prices climbed and efficiency concerns became paramount, smaller operators sought more control over drilling conditions. The result was the creation of collaborative consortia: the operators jointly establish framework conditions with the rig contractor, a well drilling company (in effect the general contractor for the whole project), and a service supplier. The aim is to make collaboration systematic, linking all relevant players in ways that allow for rapid plan revision in light of problems encountered in their execution, and the capture and subsequent application of lessons learned in each step of the drilling campaign.

The West Alpha Consortium (WAC), formed in 2009 by five operators to drill 17 wells all over the NCS in three years, was one of the pioneers of these new arrangements. The lead operator was the BG Group, a British multinational.[14] Consortium operators and the rig contractor, Seadrill, established general "safe efficiency" conditions in workshops and regular meetings before the rig began the drilling campaign. The consortium operators' steering committee hired a single, integrated service supplier, and established a core offshore team (consisting of a day and night drilling supervisor, a logistics engineer, and a safety coach), to assure key personnel continuity through the whole campaign and to allow rig counterparts to focus on urgent operational issues. Several new positions were created to ensure close and continuing planning and operational unit coordination at every well drilling phase. An "onshore toolpusher," for example, was posted from the rig to the onshore planning group, so that the current operator was abreast of rig conditions and drilling programs could be optimized in view of a full understanding of rig capacities. On the platform, a rig contractor "optimizer" was embedded in the operator's rig team to improve operational planning and execution by planning each well bore section. A "master action register," continuously updated, captured

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lessons learned and passed them on to successive operators. The WAC set a record for the fastest exploration well in Norway and operated for more than a thousand days without a lost time incident (Thistle *et al.* 2013). Petoro presents the WAC as "a benchmark for efficient drilling"(Petoro ONS Magazine 2014). A second consortium, including the BG Group and Det norske Oljeselskap (DNO), one of the NCS's most innovative firms, achieved comparable results (Ribesen *et al.* 2011a,b).

Recent developments suggest that these new practices may be diffusing to Statoil (Milne 2016). The firm participated in a new consortium with DNO and Maersk to open up the Johan Sverdrup oil field in the Norwegian Artic. Through significant collaboration with suppliers on drilling designs and practices, the consortium has been able to achieve significant cost reductions. It is too soon to say if this experiment represents a shift by Statoil to the new practices or simply the imposition of cost reductions by a powerful customer. But the participation of DNO and Maersk, two companies with broad reputations for progressive supplier relations and consortia governance, makes the experiment promising.

Whether the innovative elements of an incident reporting system in Norway, together with changes in firm organization, coalesce into a new regime that is both more efficient and less catastrophe prone than the present one is an entirely open question. The PSA could, if it chose, revise its understanding of the internal control doctrine to allow active encouragement of working groups while NOG revises its role as a trade organization to allow more active participation in the regulation informed by incident reporting. Encouraged by this rapprochement, firms might relax the remaining restrictions on the pooling of "proprietary" information on incidents. The continued success of the new consortia and the lead firms in them could then prompt a revision of the contract regime to encourage collaboration and information sharing among operators, where relevant, and between operators and suppliers. Statoil, under pressure from its competitors and learning from its suppliers, would be more inclined to fully embrace continuous improvement/incident reporting regimes that reduce risk and allow for efficiency enhancing collaboration. Unions, finally, might find a new or additional role as pillars of the incident reporting regime, giving renewed meaning to the Nordic or Norwegian model of regulation.

But of course it is equally possible to imagine a struggle to defend the status quo frustrating any of these developments, and one stalemate producing others. Deeper knowledge would only sharpen understanding of both possibilities.

7. Recursive regulation and the problem of capture

Bureaucracy and incumbent capture are the two bugbears of contemporary discussion of regulation: bureaucracy because rigid rules fixed far from the diverse contexts in which they are applied cannot hope to safeguard public values when innovation and the co-production of hidden hazards go hand in hand; incumbent capture because if regulatory policy is regularly on sale to incumbent firms the best policy will likely be to do away with regulation. But in light of changes in the last decade or more, neither seems an invincible obstacle. Developments in the microcosm of the Norwegian oil and gas industry from the emergence of incident reporting to the rise of the new consortia confirm the findings of studies from the macrocosm of organizations generally: it is possible to build institutions in which conception and execution are integrated – not separated as in bureaucratic hierarchies (Sabel 2005; Herrigel 2010). "Superiors" can adjust means and ends in response to front line "subordinates" experience of implementing initial plans or rules, and collaborating firms can learn from each other. Today it is commonplace, not provocation, to say that the traditional assumption from the sociology of work that the only alternative to hierarchy is cooperation based on mutual trust born of long association failed to anticipate a host of institutional innovations that allow collaboration between "strangers" across levels of hierarchy and organizational boundaries (Fox 1974). Examples of these new forms of collaboration are less conspicuous in the public sector. But the spread of incident reporting systems canvassed at the outset is an indication that change is coming there too – that it is taking longer than in the private sector is hardly a proof of its impossibility.

Incumbent capture has also lost much of its incantatory power. The shift in the focus of regulation from securing orderly markets to protecting the public against harms that can originate in many industries, and with new entrants as well as insiders, made incumbent protection harder to organize and less valuable. The new literature in political science shows that important cases of seeming incumbent capture are in fact the outcome of rational decisionmaking in which actors with the features of incumbents, in a general sense, receive the treatment they merit (Carpenter 2004, 2010). This is not to say that incumbents never capture regulators, but only that such capture is far from an inevitable fatality.

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But what about cultural capture, in which regulators are limited not by a covert bargain, but their own ideas? Cultural capture is especially insidious and difficult to detect and escape because it hides in plain sight in the assumptions shared more or less unthinkingly by the actors: assumptions that are ubiquitous yet invisible, like the atmosphere. Indeed, in many cases it is a misnomer to speak of capture in this connection because the culture that limits the horizon of exploration and response to risks is the product of the actors themselves. They have fallen into their own trap, not been taken prisoner by adversaries. To an indeterminate but surely not insignificant degree, the interplay of the assumptions in the tripartite system, the doctrine of internal control, and the reliance on ex ante risk analysis produced this result for a time in the Norwegian oil and gas sector. Can incident reporting and the recursive meta-regulation of which it is an indispensable part reduce the risk of this kind of capture?

The answer is a qualified yes. The assumption motivating construction of such systems is precisely that current requirements of ex ante review are almost certainly incomplete, unsuited to unforeseen contexts in which the actors will come to apply them, or otherwise faulty. This is tantamount to the recognition of uncertainty. Continuous monitoring and evaluation of incidents is then required to detect the prodromes of unforeseeable catastrophes. Investigations are triggered by breakdowns in control, which may be rooted in the limits of a particular organization, but also in gaps or errors in engineering or scientific understanding. Successive investigations make it possible to advance the frontier of predictability locally or generally. Because co-produced incidents are likely to be observed by a whole skein of actors at different levels of the organization, and in several organizations at once, and because incidents are likely to be investigated by yet other constellations of actors, the chances are slim that all will share the same assumptions, let alone the ensnaring assumptions that are common to the chief regulatory authorities and their interlocutors. Incident reporting systems, and experimentalist meta-regulation in general is therefore likely to provide in a demonstrably feasible, institutionalized manner just the cognitive diversity – rooted in difference in status, identity, and relationships – and transparency that is generally recommended as the countermeasure against cultural capture (Kwak 2014).

But this “yes” to the effectiveness of experimentalist meta-regulation as a response to the risk of cultural capture is necessarily qualified. The design of an incident reporting system –the rules specifying what counts as an incident, who is required to report one, how it is to be categorized and investigated – rest, of course, on assumptions – and those assumptions too could become snares. The discussion above of the strengths and weaknesses of various ways of disseminating the findings of incident investigations suggest the complexity of such design choices. If there can be better and worse incident reporting systems, the very worst will give a false sense of vigilance, and thus entrench rather than dislodge potentially catastrophic assumptions. And this is to say nothing of the possibility, despite the diversity of actors and the apparent difficulty of organizing conspiracies of silence or misinformation, of gaming the emergent regulatory systems for selfish purposes. In an uncertain world it would be foolhardy to assume that we can foresee the impossibility of that, of all things.

The Norwegian case surely councils caution is this regard. However general the pressure for adjustment to uncertainty, the diffusion of incident reporting there, as elsewhere, has not been spontaneous or automatic. Efforts in this direction by firms, the industry association, and the regulator are fragile, checked, and undercut at times by commercial self-interest, internal organizational politics, and interorganizational frictions. They are unlikely to be institutionalized without the intervention of a public meta-regulator capable of fostering and supporting ongoing collaboration and learning among private actors (Rees 1994). Despite growing awareness of the problem of uncertainty and the need to attend to ex post problems of implementation practice, the dilemmas confronting not only the PSA, but the NOG and the unions as well, show that lingering hierarchy, rigid role understanding, and the politics surrounding the protection of both can hamper recursive learning in the public sector even when some lead firms, despite hesitations, are willing to participate.

Perhaps the most general and encouraging – but also sobering – lesson of the Norwegian experience is that the organizational resources required for this kind of continuous collaborative learning are often generated by the very forms of collaborative production that lead to the co-production of catastrophic hazards: the same ways of working that endanger us enable us to master the danger, as when the efficiency gains of the new production consortia go hand in hand with increases in personal as well as process safety.

Thus, to judge by developments on NCS, even under the harshest conditions, the newest and most complex technology has not necessarily escaped our control. We can learn to understand the risks we create, and we can institutionalize that learning in new kinds of regulatory oversight. For better or worse we are still the sorcerers, not the sorcerer's apprentice, and responsible for what we make of our powers.

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Notes

1 Published in the Federal Register as a final rule on April 29, 2016, 81 Fed. Reg. 25,888.

2 But see the thoughtful discussion by Viscusi and Zeckhauser (2015) of post-approval monitoring of pharmaceuticals, in which they show that it is rational for the regulatory decisionmaker to rapidly adjust estimates of the safety and efficacy of drugs based on incident reports. The (institutionally disembodied) decisionmaking process is modeled as successive draws in a compound or multi-stage lottery, in which results of each round are used to improve estimates of the outcome in the next. Carpenter (2004, 2010) uses a related modeling approach to explain how the FDA learns about the characteristics or type of regulated firms. This modeling technique makes uncertainty accessible to the analysis of probabilistic risk. But in the case of the FDA and pharmaceuticals, and the other regimes under discussion here, this transformation depends on an institutional mechanism – the incident reporting system – that brings to attention conditions or states of the world that had not previously figured in any meaningful way in the list of outcomes to which probabilities are assigned. In this sense, the incident report marks the moment that potentially catastrophic uncertainty becomes visible and tractable as risk. To sample the rich current debate on the distinction practically and ontologically between risk and uncertainty, see Gärdenfors (2005).

3 For this and related reasons, Bennear discards management-based regulation as an effective response to the kinds of risks that produced the Macondo blowout, and favors instead a system of experience-rated safety deposits, to be refunded in case drilling is completed without incident (see Bennear 2012, 2015).

4 For the complex but small changes in the state's ownership share between 2001 and 2011, see Statoil 2011.

5 They saw the problems and proposed a remedy similar to NORSOK.

6 This is a variant of the "comply or explain" obligation common in the corporate governance law of many EU member states. See Financial Times (2013), FT.com/lexicon, definition of "comply or explain," at http://lexicon.ft.com/Term?term=comply-or-explain

7 This discussion of the limits of the regulatory system and the discussion of new possibilities that follows draw on extensive interviewing conducted June 2013 to July 2014 with main players in the industry, supporting associations, and the PSA regulator. We acknowledge here the tremendous support that we received from the Oil and Gas Industry Association (NOG), and the Norwegian School of Economics (NHH). All interlocutors were promised anonymity and the open-ended discussions were treated confidentially. Unless otherwise noted, our portrait of the regulatory system in Norway draws on these interviews, recordings of which are on file with the authors.

8 We omit discussion of similar information exchange fora established by the Norwegian Shipowners Association (NR), which represents mobile rig owners and cargo lines. The most prominent forum with features similar to those described in the text is the Asset Integrity Forum, which concentrates on maintenance challenges on mobile units (PSA 2014, p. 17).

9 "The oil & gas industry in general, and members of Norwegian Oil and Gas Association (including work groups like DMF, PAF, WIF) and the Norwegian Petroleum Safety Authority (PSA) in particular, are invited to provide suggestions for improvements no later than 2013-02-15" (PSA 2013). See also PSA 2014, pp 15–18.

10 In this report and the 2016 RNNP, the PSA seems to be aware of its own possible vulnerabilities and shortcomings. Compare this with the portrait of the PSA as a model of industry best practice well designed to meet the challenges it faces presented by Lindoe *et al.* (2012).

11 It almost goes without saying that the PSA is mindful that cost cutting required by the fall in the oil price puts additional pressure on HSE measures. See PSA 2016a and RNNP 2016.

12 It is notable that Aven's most recent publication is co-authored by Ingrid Arstad, an official at the PSA specializing on risk management (Årstad & Aven 2017). The article develops an approach –complexity thinking – that "can challenge how current practices relate to system boundaries and system behaviour and reveal overestimation of overview and control, exaggerated unification of what is diverse, and denial of ambiguity" (p. 121). But again, there is no discussion of how such an approach could be institutionalized.

13 Our presentation of the Shell system draws on an interview at Shell in Stavanger in July 2014. By the 1980s, Shell had realized the limitations of ad hoc limits to hazardous incidents and had begun to institutionalize frameworks for ensuring safety. The next

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step was to require that the safety frameworks be continuously tested and updated to reflect on the ground experience and error and near miss reporting. The goal, which anticipates the developments reported here, was to fuse or combine top-down and bottom-up systems to foster continuous adjustment. For a detailed discussion of this early evolution, see Reason 1997, pp. 125–156.

14 Later acquired by Shell Oil in February 2016.

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