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## **Captured by technology? How material agency sustains interaction between regulators and industry actors**

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### **Abstract**

This paper examines how environmental regulation is made operational when it legislates for modifications rather than the banning of products or substances. The continued circulation of such products draws attention to the heterogeneous conditions of their use and allows industry actors to accumulate evidence of the products' polluting effects over time. We find that this agentic quality of materials – including products and sites of application – is a vital and so far largely ignored dimension in the relationship between environmental regulation and innovation. This is captured in a process we term interactive stabilization, which describes how material agency becomes a focus for interactions between regulatory and industry actors. We develop our argument through an in-depth case study of the environmental regulation of production chemistry and identify three interactive processes: formulating regulatory principles; operationalizing these principles through technical documentation and calculation; and incremental innovation as used by chemists to address clients' varied material problems in production. We trace stabilizing and destabilizing effects across these three processes and draw particular attention to the role of uncertainty in the operationalization of precaution as a regulatory principle.

We argue that this uncertainty may lead to a form of regulatory capture that we frame as technological capture. This refers to how industry actors are able to test the limits of regulatory principles and calculations and on occasion contest these through their applied science capabilities.

Key words: Regulatory capture, technological capture, precautionary principle, incremental innovation, socio-economic interaction, material agency

JEL codes: O38; Q55; Q58

## 1. Introduction

It has been a long-standing theme in policy research that regulation can stimulate and support innovation and that businesses can return net profits from innovations undertaken in response to regulation (Porter and van der Linde, 1995; Ambec et al., 2013). Environmental regulation can tie polluting effects to products and necessitate change in product formulations, production techniques, or production and research facilities. Regulatory principles, such as the principle of precaution, provide orientations and motivations for these innovations. However, they may offer little specific guidance to regulators and industrial actors on how to make these principles operational (Klinke et al., 2006; Veal and Mouzas, 2012). Operationalizing regulatory principles through incremental innovation activities tests these principles ‘on the ground’ by bringing them into contact with a regulated product’s contexts of production, exchange, and use (MacKenzie, 2009). In this paper, we argue that a focus on operationalizing has much to offer in understanding the relationship between regulation and incremental innovation, especially from a process perspective (Callon, 2009). Our purpose is three-fold: firstly, to establish how actors make regulation operational; secondly, to assess the ways in which, through this operationalizing, industry actors’ innovative activities interact with regulation; and thirdly, to evaluate the potential consequences of these interactions.

Our contribution is to propose and develop the idea of interaction among regulators and regulated companies as a form of regulatory capture, which we refer to as ‘technological capture’. Gagnon (2016) develops this concept to explain how companies acquire a dominant competitive position by articulating and imposing technological standards and intellectual property rights. We extend technological capture to explain the interactions between a well-resourced industry, with a significant applied science base, and a trans-national regulatory commission, charged with controlling the environmental hazards of the industry’s products. We see this as a process through which industrial actors use their science and technological resources in developing solutions to regulatory demands applied across heterogeneous settings. Here companies’ efforts and experiments allow them to test, challenge, and shape regulations, albeit from a fragmented evidential base, which may lead to a weak

form of regulatory capture in the sense of being guided or mediated by the norms of applied science.

In common with recent research, we understand regulation as a process. This process is a concerted effort often instigated by governments or intergovernmental entities that develop regulatory principles and suggest ways to make these operational to other regulatory stakeholders (Carolan, 2007; Knol, 2011; Udovyk and Gilek, 2014). Following the OECD's (Organisation for Economic Co-operation and Development, 1997) categorizations, regulation includes: (1) activities within markets such as taxing goods or establishing a market price for units of hazard; (2) institutional changes such as with governments devising programs to attribute externalities to established exchanges; and (3) social and environmental programs aimed at changing actors' behaviors in the production and use of established goods and services (Blind, 2012; 2016). Market mechanisms and institutional changes can be understood as stabilizing the impact of regulation on an industry's innovative activities over time, for instance as specific products are identified and prohibited (Hardy and Maguire, 2010). Social interaction can help actors to 'develop some shared understandings and definitions about ... roles, means, and outcomes in order to coordinate their actions' (Dionysiou and Tsoukas, 2013, p. 188), which can also have stabilizing effects at the interface of regulation and innovation. However, interaction may also lead to regulatory capture, a process by which those regulated 'end up manipulating the state agencies that are supposed to control them' (Dal Bó, 2006, p. 203; Laffont and Tirole, 1991).

Economic sociologists have developed the notion of regulatory capture by examining different types of interaction, such as corrosive and cultural capture (Carpenter, 2004; Carpenter and Moss, 2014). These contributions direct our attention to actors contending with one another's expertise through their social interactions (Carrigan, 2014). Our account of technological capture adds to these contributions by considering materiality in addition to social interactions as an alternative and additional explanation for regulatory capture specifically in science-intensive industries. In circumstances where regulation attends to modifying rather than banning products and services, regulators make critical demands on the science and technology bases of those industrial actors tasked with implementing regulations (Udovyk and Gilek, 2014). In these situations, industrial actors may encounter and

cope with multiple uncertainties emanating from material idiosyncrasies in production, exchange, and use over time. Following Pickering (1995), we term this ‘material agency’. Seen from a process perspective, uncertainties may stimulate further episodes of incremental innovation and permit the testing of regulation under heterogeneous conditions. This increases the likelihood of contesting or capturing regulation through an accumulation of applied scientific evidence. Consequently, we argue that where environmental regulation focuses on products that remain in circulation, the relationship between regulation and incremental innovation is one of interactive stabilization, made and remade through interactions around material effects (Pickering, 1995).

Our paper proceeds as follows. In Section 2, we draw together extant research on the relationship between regulation and innovation. We show that in regulatory settings in which hazards are qualified and not fully predictable, the relationship between regulation and incremental innovation in particular is interactive and raises demanding questions. After explaining our methodological choices and our case setting in Section 3, we pursue the theme of regulating and innovating under material uncertainty in Section 4. Here we follow the operationalization of regulatory principles in offshore chemistry, emphasizing interaction and feedback loops. We then return to extant theoretical frameworks in regulation and innovation in Sections 5 and 6, and work through the implications of our empirical insights for research and policy.

## **2. Conceptual framework**

### *2.1 The relationship between regulation and innovation*

In what has become known as the Porter Hypothesis, Porter and van der Linde (1995) proposed that the relationship between regulation and innovation develops along a relatively stable path: from costly disruption to adaptation, enhanced innovative activity and potentially positive economic returns on innovation. In a comprehensive review, Ambec et al. (2013) argue that empirical assessments of the Porter Hypothesis have tended to be cross-sectional or two-period, and have neglected assessments that capture an innovation process unwinding dynamically in response to regulation. Similarly, Blind (2016) identifies the need for further research into the processes by

which companies react to regulation. The Porter Hypothesis envisages a relationship and therefore stability. However, in process terms, the conditions and development of such stability are issues to be addressed rather than remaining implicit in any estimated relationship.

Blind (2012) presents a macroeconomic analysis of economic growth and regulation by examining a dataset of firms drawn from the OECD. This analysis confirms Porter and van der Linde's hypothesis that regulatory disruption in the short term is followed by positive economic returns from producers' innovations developed in response to change. Kesidou and Demirel's (2012) microeconomic analysis focuses on the changing intensity or stringency of regulation and firms' capability to respond, which is associated with variations in innovation effort. Capabilities have the potential to be stable, as routines, and a basis for cumulative, sustainable competitive advantage (Nelson and Winter, 1982). Ambec et al. (2013) point out that in behavioral or organizational terms, managerial and corporate routines introduce inertia, learning and adaptation, and make space for potential economic gains in the relationship between regulation and innovation. Kesidou and Demirel (2012) assume a stable demarcation rather than interaction between regulators and regulated firms, but, as Blind (2016, p. 451) recognizes, regulations are not only exogenous to companies. The possibility of feedback across a regulatory and innovation system is important. It can account for a breakdown in what the Porter Hypothesis outlines as a linear translation from short- to long-term effects for any episode of regulation and innovation (ibid.). From a process perspective, we envisage a series of interactions that have the potential to be consistent and support a relationship, albeit one vulnerable to breakdown in the midst of these interactions. This may be particularly relevant in the case of incremental innovation, where typically such interactions are recursive.

## *2.2 Stabilizing the relationship through interactions and institutions*

Institutional researchers extend the understanding of routines and capabilities to consider a set of institutions, for example business organizations, regulators, and universities providing applied research and postgraduate training concerning regulation. Such institutions can stabilize and embed an array of interactions (Dionysiou and Tsoukas, 2013). For Paraskevopoulou (2012, p. 1069), "regulation as

an institution [is] formed through the interaction of various stakeholders and [is] continuously evolving in accordance with socio-economic changes”. She examines the development of REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) and the chemicals industry and argues that, to be successful, regulation should become an institution, indicating a specific and stable pattern of interactions and roles among its participants. Hoffman (1999) also identifies a stable pattern of coalescence among institutions and organizational routines in the chemical industry internationally, terming it an ‘institutional field’. However, in a conclusion at variance to our argument, Hoffman indicates that the institutional field produces inertial effects – another kind of stability – deemed detrimental to innovation. In a study of nanomaterials used in the chemical industry, Justo-Hanani and Dayan (2014) assess contests of regulatory regimes, including those initiated and enforced by the State and those devised under voluntary conditions by industry associations. Justo-Hanani and Dayan attribute the relative success of States as regulators to them forming and participating in interactive relationships, implicitly involving a greater variety of roles than under the voluntary agreements of industry associations.

Research focusing on interaction has developed from observing a relationship between regulation and innovation to addressing the form of that relationship, for instance as regulatory capture. Where Ambec et al. (2013) and Blind (2016) identify processes and interactions as research gaps, Carpenter and Moss (2014) argue that frequent interactions and negotiations have the potential to produce corrosive capture as producers articulate their interests to reduce the intensity or stringency of regulation. Kwak (2014) sees extensive regulator–industry interactions as leading to cultural capture, or at least cultural sharing, which could support Hoffman’s earlier conclusion of inertia. In contrast, McCarty (2014) shows that in complex regulatory settings, regulators often rely on specialized and operational knowledge and expertise from corporate actors. While this argument is broadly akin to arguments based on information asymmetry in earlier economics explanations (Laffont and Tirole, 1991), McCarty’s focus is on the potential of capture where interaction results in the accumulation of research evidence among producers. Carrigan (2014) presents similar findings in an historical study of the upstream petroleum industry in the US. He shows that regulators adopted an interactive approach, in part to contend with the specialist knowledge developed in situ by oil and gas companies and service

companies. From a process perspective, such interaction offers the prospect of learning rather than being restricted to short-term information asymmetries, capture and inertia.

Gagnon (2016) proposes six forms of corporate capture: scientific, professional, technological, regulatory, market and civil society. He defines technological capture as ‘the establishment of technological standards or the appropriation of technical knowledge through patent portfolios’ (p. 242), but limits its role to interfirm competition and domination. Given our research questions concerning the implementation of regulation, we develop the definition of technological capture as utilizing an industry’s applied science capabilities to shape or influence regulatory trajectories. Building on McCarty (2014) and Carrigan (2014), we suggest that, as a potential by-product of producers’ scientific and innovative efforts to comply with regulatory mandates, technological capture may be a weak form of regulatory capture by industry actors. In support of this suggestion, Gregson, Watkins and Calestani (2013) describe the combination of markets, government policy and regulation in the UK Ship Recycling Strategy, where the potential for market failure destabilized the industry’s seemingly stable regulatory framework. Their study identifies a series of feedbacks in the relationship between regulation and incremental innovation, indicating how this relationship can be made and remade through multiple interactions.

### *2.3 Environmental regulation and material agency*

In science and technology studies of environmental regulation, researchers have assessed how actors put regulation into practice (MacKenzie, 2009; Veal and Mouzas, 2012). Actors introduce novel and sometimes competing models, lab experiments and observations for evaluating products and their effects in relation to regulation (Levin and Espeland, 2002). For instance, Veal and Mouzas (2012) examined the operations of the European Emissions Trading Scheme. They showed how a large manufacturer challenged the UK’s Environmental Agency over its regulatory models. This challenge shifted the contest from principles and broad policy targets to the measuring systems used to implement the principles.

Researchers in science and technology studies provide a focus on the role of material effects as an impetus and focus for contests in application. Material agency highlights the uncertainties inherent in applied science and technology, as these impinge upon activities ‘in the wild’ as distinct from ‘in the lab’ (Pickering, 1995; Latour, 2009). Pickering (1995, p. 7) sees science and technology as the ‘business of coping with material agency’. His statement indicates that objects have causal or agentic properties that cannot be anticipated or grasped fully in scientific practice, owing to the experimental quality of science. This holds as true at the micro scale of individual chemicals as it does at the macro scale of socio-environmental systems. For instance, Udovyk and Gilek (2013, p. 12) write of marine ecosystems “as virtually unpredictable and prone to surprises from both social and natural factors and/or their combinations, meaning that our knowledge of socio-ecological systems and the ability to predict their future changes might not always improve even after significant research”. In this sense, Pickering (1995) argues that scientists can only artfully ‘frame’ material effects in order to contribute to an ‘interactive stabilization’ of social and material dynamics.

As an irreducible source of uncertainty, material agency has the potential to unsettle regulation, in terms of its application, and businesses, in terms of their innovation trajectories. In these cases of ‘epistemic uncertainty’, actors are advised to devote efforts to on-going monitoring and accumulating data, so at least appreciating the bounds of their understanding (Udovyk and Gilek, 2013). Interested parties can also highlight material agency as a reason for lobbying by industry (Fineman, 1998; Lohmann, 2009) or for citizen participation in regulatory processes (Udovyk and Gilek, 2014). Where multiple actors contest the calculation of material effects, the arguments and evidence may be produced in a relatively orderly manner, but they may also create significant instabilities (Callon, Lascoumes and Barthe, 2009). Different models of capturing material agency can compete with and complement one other, which actors can draw upon strategically in a process of ‘experimentalist governance’ (Sabel and Zeitlin, 2008). Thus, an experimental or participatory regulatory process may not always lead to stable outcomes (Gregson, Watkins and Calestani, 2013).

#### *2.4 Conceptualizing the relationship between regulation and innovation as a process*

We propose a conceptual framework (Figure 1) that outlines ways in which regulation and innovation may relate to one another from a process perspective. Figure 1's starting point is with actors identifying the effects of corporate activities, deemed harmful or hazardous by some, and not taken into account in established commercial exchanges (Coase, 1960). Following the OECD's (1997) typology, these might be addressed if actors acquired and enforced property rights, thus proposing a market solution. Regulation could also be in the shape of a policy intervention, banning or restricting harmful substances. Following Sections 2.1 and 2.2 (above), both scenarios contribute to stable trajectories of innovation – where stability is the ability of industrial actors to predict the scope and consequences of regulatory engagement in their activities. We focus our argument on the middle column in Figure 1: regulatory settings in which implementation and operationalizing are critical, as in situations where hazards are qualified and uncertain. Actors typically make successive moves from Figure 1's top to bottom. In so doing, they may encounter multiple dimensions of uncertainty, which we have highlighted in red in this Figure. Each of these uncertainties stimulates further episodes of interaction between regulators and those regulated. As discussed in Section 2.3 (above), research in science and technology studies provides insights into these interactions and suggests the existence of a number of feedback loops. Empirical detail is needed to address these recursive qualities and to validate this framework, which we turn to next.

[FIGURE 1]

### **3. Methods**

#### *3.1 Research design*

Our research focused on regulating, producing and using production chemistry in the North East Atlantic. It covered a period of six years, as our interests in tracing interactions between regulation and incremental innovation required a longitudinal and processual research design (Langley, 2007; Van de Ven and Poole, 2005).

When we negotiated access to a production chemistry company (hereafter ChemCo) in early 2006, our interest was in the combination of science, product development

and sales in the upstream petroleum industry. We began by undertaking a sampling exercise from ChemCo's projects database, identifying seven projects that showed contrast across client, category of product and length of project. Interviews with the chemical company revealed the move towards 'green chemistry' and its regulation to be fundamental to most of these projects (Anastas and Warner, 1998). Green chemistry provided a focus on how regulation interacted with the development and use of production chemistry. This expanded the focus of our study from a single case firm to include the wider regulatory context in which this firm operates.

Our study spanned multiple field sites: oil companies' production facilities; chemical companies' laboratories; events at non-governmental institutions and universities; conferences and trade-shows; and the regulators' offices and meeting rooms. Overall, we traced how actors organized the regulation, production, exchange and use of production chemistry in 25 instances across business and policy events (summarized in Table 1). We undertook 36 formal and numerous informal interviews. We also amassed 160 hours of intense observation at meetings, conferences, and workshops, which we understood to be places where actors shaped production chemistry and regulation. We reviewed dozens of scientific papers, policy documents, meeting minutes and commentaries from environmental groups on production chemistry, produced water, the North East Atlantic's ecosystems, the history of the OSPAR Commission and Convention (the Oslo and Paris Conventions for the Protection of the Marine Environment of the North-East Atlantic) and REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals).

[TABLE 1]

We organized our data in the software package QSR NVivo. Our initial analysis was inductive and independent across all authors involved. First readings aimed at identifying the activities, actors, materials, technologies, and texts involved in regulation and innovation. Guided by our conceptual background, we then interrogated and categorized field data against the concepts of stability, interaction, and material agency. We compared and contrasted our initial inductive analysis against these theory-led categories in a series of joint research meetings and revised our analysis where required. Finally, we presented our analysis to our research participants for further discussion and refinement.

### *3.2 Research setting*

#### *3.2.1 The production chemistry industry*

The offshore oil and gas industry, as it operates in the North East Atlantic, raises a 'wide range of environmental concerns' for regulatory bodies, oil companies, companies supplying oilfield chemical services, and environmental groups (OSPAR, 2009, p. 5). The industry relies heavily upon incremental innovation for its continuation in an era of maturity. As such, it is a valuable case site for studying interactions between environmental regulation and incremental innovation. Production chemistry is a service for the upstream petroleum industry that is offered by a small number of chemical companies. In recent years this service has gained in importance with the physical maturing of the infrastructure for oil and gas production in the North Sea. Faced with a number of mature fields and the prospect of decommissioning, few oil companies can justify replacing the production and pipeline infrastructure. At the same time, oil companies are intensifying their use of the established infrastructure by tying-in new marginal and brownfield developments. Production chemists offer services to protect infrastructure and pipelines against corrosion from seawater or blockage by scaling and waxy deposits. This service covers regular application and monitoring of chemical solutions, and early diagnosis of new problems. Production chemistry also supports oil companies by separating oil from water during the production process and protecting against microbial infections and the corrosive effects of naturally occurring substances.

Production chemists design their work to be compliant with the regulatory requirements of OSPAR and REACH, which may become more stringent over time. About half the workload of chemical companies is secured from oil companies under four or five-year Chemical Management Service Contracts, in which chemists include regulatory priorities and contingencies in annual work plans subject to quarterly reviews. Product formulation, testing, application and monitoring are some of the services that chemical companies carry out under these contracts. These activities see chemists contending with heterogeneous material problems across oilfields, many of which require on-going adaptive solutions. Chemists undertake radical innovation

infrequently owing to the complexity of the oil production systems and platform infrastructure, and risk avoidance on the part of clients' asset managers.

### 3.2.2 The focal case firm

ChemCo is the third largest, by market share, of a handful of global chemistry companies specializing in the development, manufacture, application, and supply of chemicals and services to the oil and gas industry. The company commenced business in the mid-1980s as a start-up, initially serving the UK. Since 1995 it has been part of a larger trans-national chemicals group, which gives it access to fundamental chemistry research among base chemicals. It employs about 400 people globally and operates in all major upstream exploration and production locations. The company has an extensive science base, offers a complex range of products and services internationally to customers with varying knowledge and appreciation of production chemistry, and competes in the North Sea with five other chemical companies.

The company and its competitors are in regular contact with regulators through formal and informal interactions, conferences and industry gatherings, and occasional joint industry research and development projects. The company also engages in several large academic collaborations. It runs an environmental research and testing laboratory, which addresses compliance with emergent regulation and undertakes some tests that can be used to preempt changes in environmental legislation. The labs serve oil and gas production facilities internationally, and are supported through local technical service units, which test and monitor the environmental compliance of customized products.

### 3.2.3 The regulation of product chemistry

The industry adds about 900,000 tons of chemicals annually into the oil-production facilities located in the North East Atlantic, some 250,000 tons of which are released into the sea (OSPAR, 2010a). Much of this quantity attaches itself to so-called 'produced water' that is recovered alongside hydrocarbons and, after separation and treatment, often released from production facilities into the sea. At around 400 million cubic meters, produced water represents the industry's largest waste stream and has been identified as one of the industry's environmental 'key issues' (OSPAR, 2009).

Production chemistry products and services fall under the regulatory regimes of OSPAR and REACH. The EU's REACH legislation, which entered into force on a phased basis during our initial research phase in 2007, seeks to replace a variety of national legislations with a singular system of chemical regulation for Europe. It requires companies to disclose the chemical components of products used in the EU and applies to all chemical substances that are manufactured, imported, placed on the market, or used within the European Community.<sup>1</sup>

Preceding the European Union's 2007 REACH regulation by 15 years, OSPAR has highlighted the gravity of chemical pollution and hazardous substances related to offshore activities and the necessity of members acting in a coordinated manner. OSPAR is a convention with signatories and contracting parties from the European Community and the fifteen nations with coastline on, or significant watercourses flowing into, the North East Atlantic. OSPAR's mission is to: 'conserve marine ecosystems and safeguard human health in the North-East Atlantic by preventing and eliminating pollution; by protecting the marine environment from the adverse effects of human activities; and by contributing to the sustainable use of the seas'

(<http://ec.europa.eu/environment/water/marine/ospar.htm>). This convention provides a process for its contracting parties (governments) to harmonize their regulation of the potentially hazardous substances that can enter the North East Atlantic's marine environment as a result of activities in their waters or on their land. The aim of the regulations is to achieve 'concentrations in the marine environment near background values for naturally occurring substances and close to zero for man-made synthetic substances' (OSPAR, 2010b, p. 6). OSPAR works on a consensus basis, but once a decision is adopted it is legally binding for the Contracting Parties.

#### **4. Findings**

In this section we address our research questions in the context of our case study and assess: (1) how actors make regulation operational; (2) the ways in which this process of operationalization makes the relationship between regulation and incremental

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<sup>1</sup> REACH regulations were phased in over 2007 to 2018 and thus not fully operational during our research period. We therefore decided to focus this investigation on OSPAR's established regulatory framework for offshore chemicals.

innovation interactive; and (3) the potential consequences of these interactions. For our first question, we examine the three phases of our framework in Figure 1: formulating regulatory principles (Section 4.1); operationalizing principles through manuals, calculations and proposed tests (Section 4.2); and applying regulations in product formulation, testing and use (Section 4.3). Informed by our conceptual framework, in addressing our second and third questions we identify the ways that actors contend with and utilize the uncertainties encountered across these three interrelated phases (Section 4.4).

#### *4.1 Guiding innovation in production chemistry through regulatory principles*

Hazard describes the potential for chemical substances to harm – pollute – a marine ecosystem. There are different ways of capturing how hazards cause polluting effects. OSPAR's contracting parties accept a general obligation to apply the following principles: precaution, polluter pays, and use of the best available techniques and environmental practice (OSPAR, 1992). Precaution offers a way for regulators to act on hazards in the absence of robust evidence and on the basis of worst-case scenarios. OSPAR was one of the first regulatory entities to embrace the precautionary principle, following the Rio Declaration on Environment and Development in 1992 (Knol, 2011). Precaution has wide-ranging consequences for an industry's involvement in an ecosystem. OSPAR formulates these as:

- a. the principle of substitution, i.e. the substitution of hazardous substances by less hazardous substances or preferably non-hazardous substances where such alternatives are available, will apply;
- b. emissions, discharges and losses of new hazardous substances shall be avoided, except where the use of these substances is justified by the application of the principle of substitution;
- c. the scientific assessment of risks should be used as a tool for setting priorities and developing action programmes (OSPAR, 2010b).

'Substitution' makes reference to avoiding the introduction of potential pollutants into the Atlantic ecosystem and encourages innovation at 'the beginning of the pipeline'. OSPAR and REACH aim for stringency over time, updating lists of chemicals to be substituted with chemicals evaluated as being less hazardous (Still, 2011). The substitution list forms part of the authorization process by which national government

agencies allow or disallow the use of substances offshore in accordance with OSPAR's Harmonised Mandatory Control System (OSPAR, 2000). Regulators also establish timeframes for phasing out chemicals, which provide production chemists and oil companies with an impetus to plan innovation and substitution programs.

For the 'avoidance of discharge and emission', OSPAR focuses attention on 'the end of the pipeline' (Fineman, 1998) and requires that produced water be sampled and analyzed regularly. Methods for these procedures are prescribed and acceptable limits are set and enforced. Sampling and testing produced water is typically carried out on behalf of the regulator by the oil company or their chemicals services supplier, with the data being collated and reported. When oil companies have ensured that they are producing water that is of an 'acceptable standard', it qualifies as a waste stream and can be discharged into the sea.

Through 'programs of innovation and monitoring risks', OSPAR invites innovations in product development and regulatory models and standards, and encourages industry actors to think 'beyond' the pipeline. There are advances in treating and assessing the quality of produced water intended for injection into mature hydrocarbon reservoirs (LUX Assure, 2012). These developments include sensors and monitoring tools at the nanoscale. This principle connects the qualities of production chemistry with other areas of innovation, such as the capture, removal, and reuse of chemical residues in produced water. It also calls upon chemists to continue the development of techniques and standards, as well as of products that are less polluting.

Two implications of the principle of precaution are apparent. First, OSPAR attaches the label of hazard to the chemical substance itself, removing considerations of local interactions among substance, seawater and the marine ecosystem's constituents. Second, OSPAR promotes a standard and harmonized version of the regulatory jurisdiction as a basis for enacting the precautionary principle, with the most sensitive locality standing in for the whole jurisdiction. With this, OSPAR has defined standard versions of seawater, the marine environment, and production facilities, which are used as parameters in calculating the hazardous qualities of chemicals. This allows for a definitive ranking of chemical substances in terms of hazard and provides a basis for regulators when they issue substitution warnings and orders. Both implications have a

broadly stabilizing effect on the relationship between regulation and incremental innovation. This is evident as they refer to known global testing parameters and envisage predictable patterns for substituting hazardous with less hazardous chemicals over a defined time period. However, in accordance with Knol (2011, p. 400), we note that while the precautionary principle places the burden of proof on the polluter, precaution is also open to “much ambiguity as to what that ‘proof’ consists of”.

#### *4.2 Operationalizing regulatory principles*

OSPAR writes and deploys documents to establish a process by which precaution and hazard are made operational in guiding industrial activities. Some documents are co-authored and others invite consultation, so they are both locations and means of interaction and consensus. The documents help actors settle controversies and establish the terrain covered by the settlement, for example with OSPAR it is the North East Atlantic. Critically, the documents establish the methods and measures by which the hazards of chemicals should be calculated.

The key operational document presents a model known as Chemical Hazard and Risk Management (CHARM) (Thatcher et al., 2005). CHARM began as a joint-industry project among participants across OSPAR member nations. The resulting document is co-authored by regulators and production chemists working for oil and chemicals companies. CHARM assists regulators in defining the quality of hazard associated with chemical substances used in production chemistry. Chemicals are subject to ranking along a single index of hazard, the ‘Definitive Ranked Lists of Approved Products’. Each chemical substance – a component in a chemical product – is tested against the criteria for persistence in marine water, bioaccumulation in the lipids of organisms, and toxicity to marine organisms at three different positions in their food chains (OSPAR, 2005-9). The criteria are used to gauge the hazardous nature of a substance. The industry users must provide data related to the individual substances to the authorities that determine whether they can be used and discharged.

CHARM comprises four modules. It’s first and second modules implement precaution through ‘realistic worst case scenarios’ to direct the use of chemicals in production facilities. In order to calculate a ranking of chemical substances according to the criterion for environmental hazard, CHARM requires deterministic calculations of the

ratio 'PEC/PNEC' (predicted environmental concentration relative to predicted 'no effect' concentration).<sup>2</sup> In the more recent third and fourth modules, CHARM provides a risk calculation that takes into account the local conditions of a production facility and a risk management model in which 'preparations' (combinations of chemicals as products) can be modelled. CHARM envisages different versions of PEC/PNEC across its modules as bases for calculating environmental hazard or risk and as a guide for risk management. Only in its 'precaution' version (the second module) can CHARM provide a unique ranking of substances because of the standardizing assumptions made as to subsea conditions and typical production facilities (Millais et al., 2011).

In summary, CHARM aims to provide a vehicle for industrial actors to translate and implement the principle of precaution. In recent times the document has evolved from operationalizing the principle of precaution to guiding calculations on environmental harm based on the principle of risk. Calculations based on the principle of risk typically include a local assessment of hazards and often represent a lower threshold for chemical products to be cleared for use. This trajectory across its modules indicates an evolving knowledge base and potentially interactive regulatory process. It also opens up the document and its models to further challenges and development, as we will discuss below in Section 4.4.

#### *4.3 Putting regulation to work: Product formulation, testing and use*

In formulating, testing and applying chemical treatments compliant with OSPAR regulations, chemists are undertaking applied science. We observed notable heterogeneity in the problems encountered by chemists, as they contended with an oilfield's specific geology and a production facility's changeable chemical regime. Chemists sample the chemical regime of a production facility, usually in order to represent it in the lab on-shore and undertake tests for new chemical treatments. In the main, they conduct tests and experiments to assess the effectiveness of modified

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<sup>2</sup> The PEC numerator of the ratio calculates the marine environment's exposure to a chemical. The PNEC denominator of the ratio is an estimate of the sensitivity of the marine ecosystem's species to a particular chemical. The PNEC is recorded in standard lab tests as the highest concentration at which researchers expect no adverse effects. If the PEC/PNEC ratio is greater than one, "an environmental effect may be expected". The model allows two hazard quotients to be estimated: for a suspension in seawater and for sediment on the seabed. Rather than calculating an average, the greater value is taken, which is a further instance of the application of precaution (Thatcher et al., 2005).

treatments, compare feasible solutions to new problems, optimize the dosage in application, and assess the environmental hazard of a product. Across the production chemistry industry, tests are also undertaken by commissioned research institutes and independent labs (for instance SINTEF in Norway).

We discuss three of our sample projects to illustrate how industrial chemists use incremental innovation when dealing with environmental regulation and customers' site-specific production problems. Our first project (Project 5 in Table 1) shows how production chemistry can require fundamental as well as incremental innovation in order for products to meet regulatory criteria. The project involved ChemCo's parent company developing a new chemical base so that ChemCo could, in turn, develop a less hazardous corrosion inhibitor for an oil company's pipeline. Pipelines are vital infrastructure, given the industry's maturity, and require maintenance through chemicals management to ensure what the industry calls 'asset integrity'. The project related to earlier work that was partially successful and paused after a chemical substance was downgraded in terms of hazard, no longer attracting a substitution warning. A further change in the ranking of that substance, under OSPAR's Harmonized Chemical Management Regime, led to a renewed substitution warning and the resumption of the project. The incumbent corrosion inhibitor had eight component substances, and, by the time the project commenced, three had attracted substitution warnings and needed to be replaced. This project demonstrates the extent to which both fundamental and incremental innovation are motivated by periodic regulatory changes in a traditionally risk-adverse industry. In this industry, new or modified chemical treatments represent an unknown quantity as to how they might react with other chemicals or naturally occurring substances when applied in practice.<sup>3</sup>

Chemists face material challenges in adapting their treatments to novel technical problems as well as to environmental regulation, as illustrated in our second case (Project 2 in Table 1). In this case, ChemCo had lost a contract to supply a corrosion inhibitor following a substitution warning from the regulator. The modified product was less hazardous and less effective when applied to the client's facility, which included a novel subsea installation. Subsea installations at depth are challenging

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<sup>3</sup> In our interviews, operations and asset managers were particularly slow to be persuaded to allow changes in chemical treatments in an oil field under their management.

settings for production chemistry because rapid temperature changes place additional stress on the stability of chemical treatments. A rival corrosion inhibitor had greater stability across the range of temperatures, but had a negative impact on the production system's demulsifier. This meant a less effective separation of produced oil and water and an increased pollution hazard from production. The oil company needed a quick fix to the problem and was keen to deploy a modified version of ChemCo's original product, for which improvement in stability could be made on the condition of seeking regulatory and time-limited approval. However, within the short time frame provided, ChemCo could not economically produce the modified corrosion inhibitor for this single application. This case draws attention to the difficulties created by regulating on the grounds of individual chemical hazard rankings, for which agreed test protocols have been established. In actual application, chemicals interact with a production system as part of a composite treatment regime, often with unpredictable consequences on the oil system and the environment.

A third case (Project 7 in Table 1) illustrates the complexities of undertaking oilfield chemistry in a mature regulated industry. In oil and gas production, maturity presents many problems, such as corroding infrastructure, chemical accumulation from prior treatments and high levels of water in oil for near-exhausted oilfields. Oil companies often have to re-engineer oil and gas fields as they mature in order to maintain the production rate. The customer in Project 7 had acquired the oilfield and was re-engineering its production infrastructure. A number of small problems had emerged, including microbial infection, which degraded the oil and increased its level in the produced water to slightly above the regulator's limit of 30 mg/l. The problem of oil-in-water could be treated using chemical demulsification alongside mechanical solutions. In addition, the microbial infection could be treated chemically through biocide products, but owing to their toxicity the regulator had banned the most effective of these treatments. Added to this problem, the permissible biocides tend to interact with demulsifiers and corrosion inhibitors, and can lead to excessive amounts of oil in produced water. Demulsifiers work quickly and, after an initial screening of alternative solutions in the lab, the chemists carried out tests live on the oil platform. However, 'in the wild' the tests provided inconclusive results as the facility's chemical regime had changed quickly over multiple dimensions. In this case, adaptations in production chemistry met OSPAR's regulatory standard for chemical

hazard but had detrimental effects on the quality of produced water, which created another hazardous effect. In addition, the material conditions around the mature platform changed too quickly for the treatment's effects to be established conclusively.

The three projects' activities show that in attributing hazard as a deterministic quality to individual chemical substances, regulators motivate incremental innovation around developing and manufacturing 'less hazardous' chemicals. 'In the wild', however, these substances are typically applied as multi-component chemical treatments under varying local and often rapidly changing conditions. The chemicals become sources of material agency and uncertainty as they interact with one another, naturally occurring substances, and produced oil and water in ways that are unpredictable and frequently create additional effects and environmental concerns elsewhere in the system. Often, one episode of product development leads to multiple subsequent ones. The three projects also demonstrate that in application, controlling chemical hazards effectively requires trade-offs between treatment regimes exhibiting different profiles of risks.

#### *4.4 How material agency destabilizes regulation*

We have illustrated how precaution is the guiding principle of OSPAR's regulatory and scientific discourses. As outlined in Section 4.1, regulating by reference to precaution involves regulators providing guidance on chemicals' environmental hazards. It also requires industrial chemists to engage in incremental innovation, in order to develop and apply regulation compliant products. Regulation and innovation could thus be related in a relatively linear process. However, the relationship is less stable when users acquire, accumulate and circulate an evidential basis that can challenge regulatory assumptions about the hazards of chemicals. In our case, chemists' evidence drew upon local data collection and simulations in labs and was therefore fragmented. Nevertheless, it provided sufficient grounds for oil and chemistry companies to begin challenging regulatory principles. Some industrial chemists argued that their data shows that the marine environment presents heterogeneous conditions locally, such that what may be hazardous in and around one production facility may not be so at another. Given the continuing uncertainties as to the precise calculation of environmental hazards and in the light of evidence

underlining some of these uncertainties, the chemists proposed risk assessment rather than precaution as an alternative basis for regulation. Precaution and risk also entail significant differences in ways of stating assumptions and calculating the hazards of chemicals. While precaution is based on global parameters, risks are calculated as interactions between a chemical substance and its local conditions at the site of application. The principles imply different ways in which regulators and chemists interact, for instance in gathering and combining fragments of data, and in stating assumptions about hazards (Carolan, 2007; van Hoof and van Tatenhove, 2009).

Industry actors drew upon principles in conjunction with the experimental field data as a way of contesting some of the regulatory documents, for instance by organizing multiple forums on the subject of precaution and risk. We attended several of these, which included national regulators involved in OSPAR and the European Chemicals Association as part of the REACH process. Applied chemical scientists also presented case studies at professional conferences, such as those organized by the Society of Petroleum Engineers and by the Royal Society of Chemistry, which have regulators in attendance. At these forums, data were not so much mobilized to challenge regulation over adjusting the specific operationalization of precaution in CHARM, but rather used as a basis for the much more far-reaching challenge of replacing precaution – OSPAR’s foundational principle – with a risk-based approach. In other words, chemical companies felt they had collated sufficient data to substantiate their concerns over investing in compliant chemistry processes, substances, and products to reduce hazards that may not be manifest in many local instances of product use.

In response to these challenges, following considerable discussion, and encouraged by the overlapping developments in REACH (European Chemicals Agency, 2008, 2012), OSPAR has recently published its CHARM Modules 3 and 4 (OSPAR 2012a, 2012b) as recommendations. In these modules, OSPAR has made risk into an operational practice alongside precaution, notably by providing procedures for the calculation of local effects measured as ‘exposure assessment’. This extension of hazard to risk has encouraged others to develop alternative algorithms, which are probabilistic in their local applications (Karman and Reerink, 1998; Millais et al., 2011) and further promoted risk as an alternative driver of chemical regulation in offshore settings. Thus, a consequence of site-specific problem-solving is that chemists test the limits of

environmental regulation in a number of settings and under various conditions, which they can then bring to challenge regulation in terms of principles.

## **5. Discussion**

### *5.1 Summary of Findings*

Our findings suggest that it is important to understand the process by which environmental regulation is made operational, as this is integral to capturing the relationship between regulation and incremental innovation (Ambec et al., 2013; Blind, 2016). We show that this process is not only a matter of regulators drawing upon a science base to document appropriate tests and stages of approval. Researchers have argued that environmental regulation may be prone to multiple sources of uncertainty, which justifies adopting a process approach (Knol, 2011; Udovik and Gilek, 2013). Indeed, in the cases we investigated the uncertainties were profound. In contrast to other chemistry fields, such as those related to Persistent Organic Pollutants (Hardy and Maguire, 2010), many production chemicals remain in use in modified form, with use continuing to generate additional data. Even though these data points were generated opportunistically by industry actors in the course of chemical development and application, they have the potential to undermine the very principle – precaution – upon which OSPAR’s regulation and guidance to industrial actors is based.

### 5.2 Research contributions

#### 5.2.1 Material agency

De Vaujany et al. (2015, p. 3) note that ‘Regulation appears as an ideational, often discursive, set of practices.’ With our study, we draw attention to material agency and its potential effects on regulatory principles. The extent of documentation in our case shows that, as a principle, precaution is not applicable singularly in guiding the development and use of production chemistry. To recall, some chemists draw on evidence of heterogeneous material effects to contest the feasibility of a definitive ranking system that identifies hazards with specific chemical substances. The science base of applied production chemistry is mainly located within companies, which is a

common basis for established understandings of regulatory capture supported by information asymmetry (Carrigan, 2014). Chemists undertake applied work as a series of short projects, typically yielding incremental innovation, in response to regulatory changes and heterogeneous challenges emerging from oil companies' production flow and maintenance. Much of the chemists' problem-solving is bound by commercial confidentiality and embedded in specific business-to-business relationships, forming a fragmented evidence base.

However, that same evidence is subject to common and therefore stable testing procedures, including those recognized by regulators, which increases the potential for combination and comparison of results. On occasion, chemists are able to draw upon their fragmentary findings, reinterpreted as field or lab experiments, to work through the consequences of adopting and applying the rival principles of precaution and risk. Applied chemists also draw upon the research base of universities and research institutes for longer joint industry projects. The conferences of the Royal Society of Chemistry and the Society of Petroleum Engineers provide forums for chemists to operate at arm's length from their company role. Some university researchers are also active at these conferences. Thus, similar to previous research findings (Hardy and Maguire, 2010; Hoffman, 1999), the institutions of applied chemistry provide a basis for contest and challenge as part of the regulatory process, with interactions in our case spanning knowledge sharing, market exchange, adaptations of products to regulation, and discussions of regulatory principles. In contributing to this research, we highlight that where our findings indicate a pattern of social interaction, these interactions are often motivated and sustained by material agency (Pickering, 1995).

### 5.2.2 Interactive stabilization

In answering our research question of how regulation is made operational, we identify a process of interactive stabilization. The relationship between regulation and incremental innovation unfolds as a matter of recurring organization, which is distributed among regulatory and industrial actors. Stability has multiple meanings in regulatory theory and practice, from analytical or modelling assumptions to empirical observation (Blind, 2012; Kesidou and Demirel, 2012; Justo-Hanani and Dayan, 2014). We find that actors go about achieving stability recursively and mainly through

the processes of documenting agreements, be these in regulation or commercial contracting. Stability is in the web of interleaving documents rather than in one document per se (Paraskevopoulou, 2012).

The stability and predictability of regulatory phasing is necessary for industry actors in order to plan the development and marketing of chemical products and services. These regulatory changes generally take the form of advance notices of amendments in CHARM's definitive ranking of chemicals by hazard. For industry actors, this is made more complex by production chemistry being subject to two regulatory processes, which at the time of our fieldwork were not fully harmonized. While OSPAR is interested primarily in hazards posed to the marine environment, REACH requires disclosure of the chemical components of products, which causes great concern to industry actors as it allows others to view the outcomes of lab work on devising specific chemical treatments. With its emphasis on products rather than chemical components, the REACH process provides an additional impetus for companies to refocus their attention on the principles of risk and precaution. This undermines the way in which OSPAR has translated precaution into its regulatory process based on ranking the hazards posed by particular substances.

### 5.2.3 Technological capture

In our findings, we identify two ways in which industry actors cope with uncertainty: (1) the collation of scientific and technological data as evidence in response to the material agency of the industry's products and services; and (2) the social interactions and contests in relation to policy, enabled by material agency. Taken together, we characterize these as instances of technological capture (Gagnon, 2016). Given our conceptual framework, we develop technological capture by applying it to a processual explanation of the relationship between regulation and innovation, and refine and validate it in our case study. Regulatory capture, the focal construct of recent research, features little by way of interaction around material effects. Social or cultural capture (Carrigan and Coglianese, 2011, 2014; Kwak, 2014) is consistent with institutional regulation, as per Hardy and Maguire's (2010) study of policy-making in the banning of persistent organic pollutants. Corrosive capture (Carpenter, 2014) describes how well-resourced industry lobbies attempt to dilute stringent and costly regulatory requirements. Our findings qualify the corrosive role of industry

interests. If there is corrosive capture, it is motivated by material effects and enabled by an industry's applied science expertise, both of which are prominent in the domain of environmental regulation (McCarty, 2014). In short, we claim that resistance to and potential capture of regulation often happens by applied science testing it on the ground and addressing dynamic material effects through incremental innovation, thus working with and against regulation in a nuanced interactive process. We acknowledge, with Carrigan (2004) and McCarty (2014), the possibility that the interactive relationship we describe is also a learning relationship, in which regulators rely on the industry's science base for knowledge accumulation. We would encourage future research to investigate the bounds between scientific knowledge sharing and technological capture in more detail through other research sites and methods.

### *5.3 Policy Implications*

Our paper focuses on the relationship of regulation and incremental innovation. The process of interactive stabilization that we identify raises important policy questions. The EU has been developing a broader integrated approach to marine stewardship, driven by fisheries and shipping policy as well as hydrocarbons exploration and production (van Hoof and van Tatenhove, 2009). The impetus from the EU is explicitly to include concerned publics into its regulation and application (van den Hove, 2007). Udovyk and Gilek (2014) concentrate on the implementation of REACH for the marine environment. In parallel to our findings, they identify significant uncertainties and fragmentation in relation to the science base. Assessed from a perspective of 'post-normal science' where facts are uncertain and stakes are high, Udovyk and Gilek argue that greater participation can help challenge and direct science towards more effective problem-solving and encourage a greater array of experimental activity. We develop this insight by showing that fragmentation is driven by practical problem-solving pertaining to material effects and, most immediately, varied commercial interests, which can spill over into some expert forums. Thus, with Carolan (2007), we encourage a stronger recognition of the need for developing 'citizen science' expertise in order to contend with technological capture, perhaps as part of non-governmental organizations' efforts to retain or build out a science capability.

A related policy development is the EU's model of Responsible Research and Innovation, which is written into the Horizon 2020 program. Often the concerns of science and policy focus on regulation and its evidence base, principles, and participation. However, Owen, Macnaghten and Stilgoe (2012) write of responsible research and innovation in shaping requirements rather than regulating effects. This goes beyond the scope of our paper but points towards broader societal questions of 'how the targets for innovation can be identified in an ethical, inclusive, democratic and equitable manner' (ibid., p. 754). Responsible innovation indicates a need for a more developed policy on energy production and use, contingent upon the maturity of hydrocarbons production offshore, fluctuating prices, and considerations of the eventual decommissioning of production infrastructure. Researching this issue in relation to how society and governments may direct an industry's efforts at radical innovation would also address a limitation of this paper, which considers interaction, material agency and technological capture in the context of incremental innovation.

## **6. Conclusions**

Our findings highlight the role that applied science and data can play in shaping evolving environmental regulation. We describe this as a process of interactive stabilization and assess it in terms of an industry's incremental innovation activities. We have shown that regulation through the precautionary principle, as in our case through OSPAR, is inherently interactive in its operationalization. Its actors are likely to encounter uncertainty by means of these interactions, notably through the contingency of undertaking science 'in the wild'. This uncertainty provides an impetus for incremental innovation to industry actors, who work across principles, documents and activities to comply with, challenge, and shape evolving regulatory demands. Material effects or, with Pickering (1995), 'material agency', draw our attention to regulators' dependence on continuing advances in applied science and technology. This is evident as companies in the industry test regulations in product formulation, exchange, and use. Material effects lead to interactions not just around issues of regulatory implementation, but also on the overarching principles of regulation. The level of interaction in our case may even be greater than in other studies of regulation and innovation (Kesidou and Demirel, 2012; Justo-Hanani and Dayan, 2014), partly because many products remain in use, although modified in

response to regulation. Thus, in keeping with Laffont and Tirole's (2001) observation that research into regulation should be industry specific, the focus on material effects provides a boundary condition for this paper's general contribution, pertaining to the continuing involvement of applied science in regulatory processes. While our industry case is distinctive in the extent to which material effects give rise to regulatory challenges on the part of industry actors, we suggest that it may be one example of several industries where the main science base resides in industry, and particularly in well-resourced large-sized or specialized firms. In these cases, the potential of technological capture of regulation through an industry's applied science base is a real and pressing one, which deserves further attention from researchers and policy makers.

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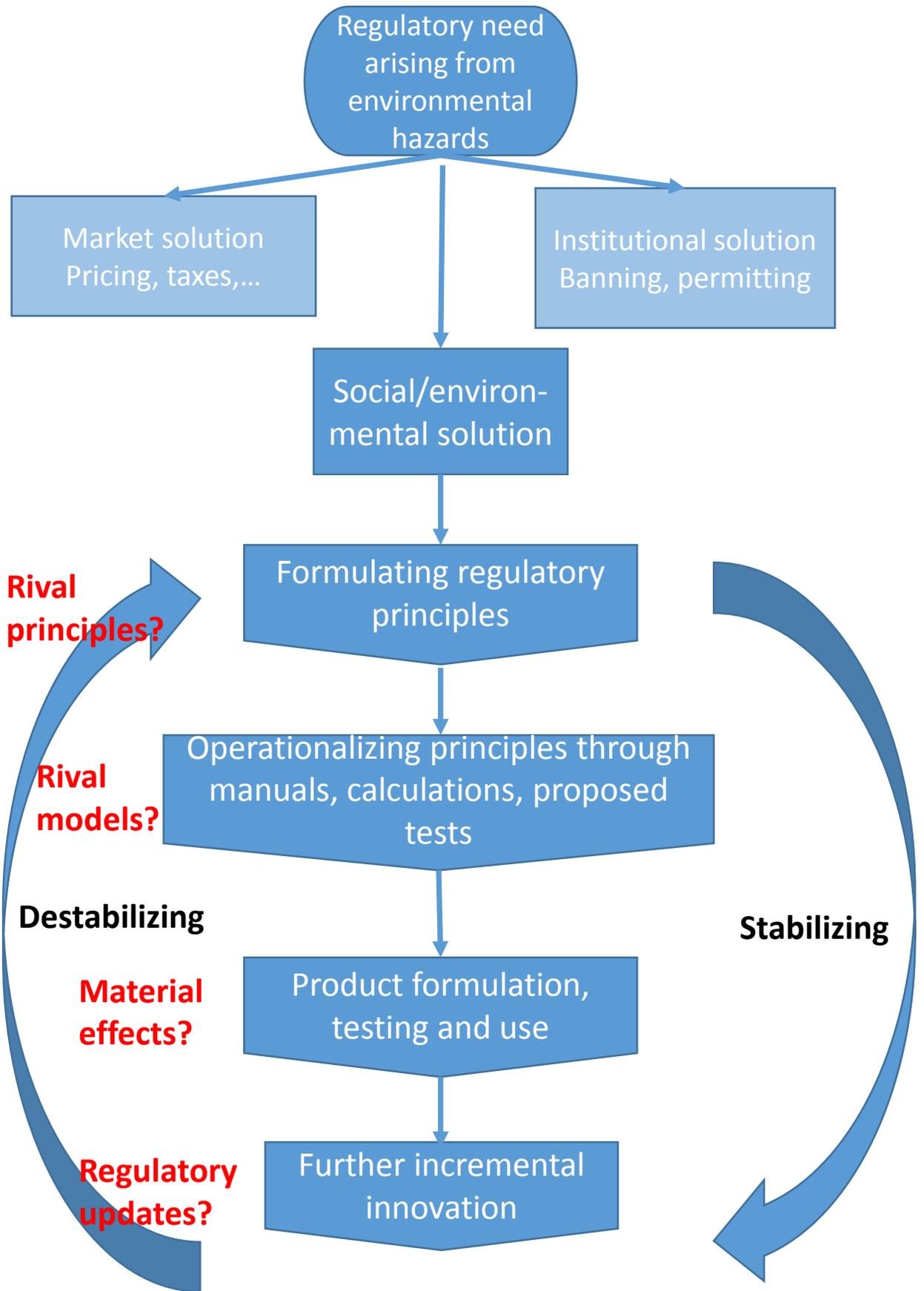
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**Figure 1: Conceptual framework**



**Table 1: Log of data collection**

<b>Year</b>	<b>Event</b>
2006	Introductions to ChemCo, interviews with Senior Management, laboratory visits
2006	<u>Project 1:</u> Adapting a product for a large oil company; interview and documentary trail
2006	<u>Project 2</u> Product testing with OilCo 2; interview and documentary trail
2006	<u>Project 3</u> ChemCo's US marketing group instigating deep water chemical innovation; interview and documentary trail
2006	<u>Project 4</u> Deployment of existing product in small oil company client; interview and documentary trail
2006	<u>Project 5</u> Corrosion project for OilCo1's pipeline; interview and documentary trail
2006/7	<u>Project 6</u> Innovating for a new way to apply production chemicals; interview and documentary trail
2007	<u>Project 7</u> Change in existing product with repercussions across sales, production and logistics; interview and documentary trail
2006	Quarterly review meeting with OilCo1
2007	Follow-up meeting with ChemCo and OilCo1
2007	Quarterly review meeting with OilCo 2
2007	Follow-up meeting with ChemCo and OilCo 2
2008	Society for Petroleum Engineers Oilfield Scale and Corrosion Conferences (2x); observation and conference documents
2008	Meeting with the Secretary of the European Oilfield Speciality Chemicals Association, subsequent email exchanges with Chair and Secretary
2009	Produced Water Workshop, Edinburgh, 2 days; observation and conference documents
2011	Meeting with European Oilfield Speciality Chemicals Association and a production company
2012	Royal Society of Chemistry and UK Chemicals Stakeholder Forum, jointly held workshop on socio-economic assessment for REACH authorization; observation and conference documents
2012	UK Chemical Stakeholders' Forum meeting, including an address by the Minister of the Department for Environment, Food & Rural Affairs; observation and conference documents
2012	Meetings with 2 consulting companies and 1 production company
2012	Interview with produced water expert

2012	European Chemicals Agency Stakeholders' Day; observation and conference documents
2012	Helsinki Chemicals Forum 2012 (2 days); observation and conference documents
2012	Meeting with UK's Department of Energy & Climate Change, Centre for Environment, Fisheries and Aquaculture Science and Marine Scotland
2012	Meeting at Greenpeace Science Unit
2012	OSPAR Secretariat (4 days); interviews and observations