Regulation fit-for-complexity

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Regulation struggles with the ambiguities, pace and trans-boundary nature of risks in our highly interconnected world. The emergent behaviours of complex systems cannot be controlled or predicted in the sense that typical causal logic or reductionist analysis would suggest, or that laws and regulatory practices often rely on. This new reality presents a profound challenge for policymakers, and a powerful catalyst for regulatory innovation.

Key messages:

- The inherent characteristics of laws and formal rules (regulations) makes them unlikely to cope with the realities of complexity. It will be important to think in terms of regulatory systems, and to use the full breadth of regulatory tools available to governments and regulators.
- What is most needed, even more than any new regulatory tools, is a new mindset that is fit-for-complexity. This new mindset requires acceptance that complexity will be navigated (as opposed to controlled), with regulatory systems explicitly designed for anticipation and adaptation.
- Navigating societal uncertainties and disruption also places an even greater premium on inclusiveness, perceived fairness, and trust as essential lubricants of regulation fit-for-complexity.

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Executive summary

Regulation struggles with the ambiguities, pace, and transboundary nature of risks in our highly interconnected world. Yet the stakes are higher than ever, with the consequences of regulatory failure being potentially immense. When risks crystallise, they can cascade from one domain to another, potentially compounding the issues as they do so. This new reality presents a profound challenge for policymakers, and a powerful catalyst for regulatory innovation.

This review explores potential responses to five different, but interrelated, attributes of complexity:

- **Unpredictable cause and effect:** relationships and interactions across highly interconnected systems are ambiguous, emergent, and dynamic, therefore unpredictable. This undermines accountability, regulatory enforcement, and the ability to apply credible controls.
- **Misaligned boundaries:** statutory mandates set boundaries that confer regulatory legitimacy. In highly interconnected systems, risks transcend such boundaries, resulting in confusion or gaps.
- **Disruptive innovation:** by its nature brings extensive uncertainty, often with significant information asymmetries (for example, between innovators/regulators) and/or competing interests.
- **Mismatched timeframes:** pace of technological innovation far outpaces institutional inertia. This is compounded by obsolescence and very different old and new regimes operating concurrently.
- **Societal confidence:** how do regulators retain their 'licence to operate' and trust in the face of societal and/or political polarisation?

Regulatory systems are highly contextual; so there is no 'one size fits all' solution.

Existing regulatory methods will undoubtedly evolve and be augmented by adoption of innovative technologies such as Artificial Intelligence (AI) and sensor networks. However, laws and formal rules (regulations) are unlikely to fully address complexity. By nature, laws need predictability, an ability to demonstrate causality and are framed by precedent. This is at odds with the emergent behaviours, multiple actors, and dynamic interactions inherent within complex systems.

We may therefore see 'hard powers' (for example, formal rules, enforcement) used in more specific and targeted ways, with increased emphasis on 'soft powers' (for example, influence, coalitions, data sharing).

The review concludes that what is most needed, even more than any new regulatory tools, is a new mindset fit for this disruptive age.

This new mindset means:

- **Acceptance that we navigate rather than control complex systems.** The illusion of control is particularly dangerous. We must remain alert to the realities of fast-moving, highly interconnected systems where solving one problem can surface other unexpected issues. That means instilling chronic unease and recognising when old methods become irrelevant.
- **Acceptance of the need for adaptive regulation.** This requires strengthened anticipation. It could also involve novel polycentric approaches that integrate the formal oversight and direction setting of a regulatory authority, with devolved mechanisms that draw on expertise, practical know-how and pace from independent self-regulation or governance frameworks.
- **Acceptance that we cannot tackle complexity in silos.** It requires collective understanding and collaborative working, from a breadth of individuals (including from outside established institutions) and a range of disciplines. Complexity places a much greater premium on inclusiveness, perceived fairness, and trust as essential lubricants of regulation.

We can and must prepare for disruption while we have the intellectual and temporal resources to do so. Global debates on topics such as AI, autonomous systems, and climate change all offer impetus for regulatory innovation. In taking these opportunities forward, this review emphasises the need for a new mindset, with leadership and collective awareness of the issues and stakes, to make meaningful progress towards regulation fit-for-complexity.

Introduction

As we look to the world around us, we see society and governments grappling with the use of regulation to tackle wide-ranging threats and opportunities such as: AI and powerful global technology companies; ever more frequent extreme weather events and responses to climate change; innovations that can barely be imagined as nano-bio-info-cogno technologies (NBICs) converge; and the economic and societal aftermath of a global pandemic.

In short, efforts are being made to apply regulatory tools to issues characterised by:

- more uncertainty in a world that strives for certainty
- more surprises, a consequence of the emergent behaviours seen as issues interact, amplify, and cross hitherto neatly-defined boundaries
- more pace in decision-making enabled by, and in response to, technological advances
- more fragmentation, with issues more visible and legitimately competing views
- more chaos, especially as contradictions of the old and the new play out in transition (whether, for example, technologies, regulatory models, capabilities, or mindsets).

By contrast, many successful regulatory systems and legal frameworks focus on tackling specific harms, based on the premise that you can predict and control how associated risks develop. In a highly interconnected world, with multidimensional risks and unpredictable emergent behaviours, that narrow framing loses relevance. Established concepts of risk control can become largely unachievable.[1,2]

In addition, the implications of any regulatory failure are likely to be of a different order of magnitude because when risks crystallise within an interconnected system, they can cascade from one domain to another, potentially compounding the issues as they do so. This was clearly seen in how COVID-19 played out, as well as in many infrastructure failures triggered by extreme weather conditions in which issues rapidly cross physical, natural, and social boundaries.

Purpose of this review

Our primary aim is to heighten awareness among policy- and decision-makers across government, regulators, judiciary, and industry that complexity calls for fundamentally different mindsets about regulation.

The review outlines how different aspects of complexity can undermine existing, previously successful, regulatory practices, and identifies potential options for responding to the associated challenges. However, regulation is highly contextual. There is no single, simple answer and no single design that will make all regulatory frameworks 'fit-for-complexity'. Indeed, some existing and previously successful designs may be rendered obsolete by rapidly advancing complexity.

Framing the question

This section sets out some of the key terms and concepts used, as well as outlining the scope of the review and approach taken.

Complexity

Complexity is characterised by emergent behaviours that are dynamic, unpredictable and often ambiguous (in part due to the plurality of perspectives involved). These behaviours cannot be controlled in the sense that typical causal logic or reductionist analysis would suggest. The absence of predictable cause and effect undermines established regulatory concepts such as 'dutyholder' (accountable for say, safety) and 'polluter pays'. Complexity can also over-extend the previously successful analytical, scientific, and risk-management practices that support regulation, making them no longer fit for purpose.

Emergence is one of the central characteristics of complexity. Within a complex system, multiple diverse interconnected actors each make decisions that shape their actions. They behave in ways that interact with the behaviours of other actors, both within and beyond what is perceived as the system boundary. They share information through tangible and intangible connections that operate at multiple levels, and continuously modify their behaviour in response to the changes taking place around them. System behaviours 'emerge' from these interactions. The whole system cannot be understood by simply looking at its individual parts. With high levels of interconnectivity and interdependencies, emergent behaviours can often drive unexpected or surprising step changes in behaviour.

Multidimensional risks are often evident – the phenomena whereby risks in one domain (or time frame) can have impacts across different domains (or time frames) through disruptions such as cascade, common cause, or escalating failures. When these risks interact, they can compound the issues to produce a consequence greater than the sum of the individual risks.

System behaviours can cross 'tipping points', beyond which any significant changes cannot be easily reversed. In addition, the existence of multiple different but equally legitimate viewpoints creates substantial ambiguity (another significant feature of complexity).

Regulation and the regulatory system

We use the term **regulation** to reflect the act of shaping business and/or individual behaviours linked to a business activity, capability, or sector to achieve some desired public interest outcome. This definition extends well beyond setting and enforcing formal laws and rules (the specific regulations). There are, for example, many other informal interactions between organisations and people that, together with formal laws, contribute to achieving the intended regulatory outcomes.

Regulation takes many forms. Examples include:

- regulators overseeing the performance of an entire sector such as water or electricity supply, or of activities such as rail or air travel
- economic regulation to protect the interests of consumers, to promote market competition, and to make sure privatised companies can properly carry out and finance their statutory duties
- safety, environmental, or product regulation to prevent harms to people or the environment, which may also involve ensuring the professional competence of those involved.

In addition, and notwithstanding any principal objectives a regulator may have, there will be broader expectations of regulatory support for government agendas such as economic growth, net zero, and innovation.

The regulatory system describes the totality of those organisations involved (supporting or on the receiving end of regulatory activity), their interactions, and the regulatory tools applied to achieve a given regulatory outcome. As noted above, regulatory tools include both the formal laws and rules that are set and enforced, and a wide range of informal mechanisms (including use of industry standards, data sharing, partnerships, or other forms of influence). An overview of these tools is provided in Annex A, with further details provided in our previously published Foresight Review.[1]

Importantly, regulatory systems are highly contextual and dynamic. They are shaped by history and by external factors such as political contexts and influences that are themselves changing.

In practice, day-to-day regulatory focus will tend to be on issues found at the level of discrete organisations, networks, or assets where risk management and performance can be more readily assessed and individuals (or relevant legal entities) can be held to account. It can also involve responding to a specific risk that has crystallised, such as repatriating travellers in the event of airline failure. Or regulation can be used to encourage innovation and shape futures, such as setting and then enforcing a timeline towards more demanding standards such as reduced vehicle emissions or better air quality.

The system of interest (SOI)

We start with the premise that regulation has a clear purpose. Thus, in considering the use of regulation, there will be a problem to be tackled (or desired outcome to be achieved). The **system of interest** (SOI) maps those organisations, activities, and interactions that are of greatest relevance to the problem (or desired outcome) being addressed. Some examples are included in the section 'Scope of this review' below.

Logic would suggest alignment between a well-designed regulatory system and the SOI being regulated. However, in practice, the boundaries of the SOI are likely to be unclear and potentially indeterminable: even knowing what the SOI is may prove challenging in complex environments (and as it changes over time). In addition, the dynamics of the two systems (SOI and regulatory) can be very different, with associated changes leading to their divergence and misalignment.

This mismatch is compounded by different stakeholders (government, regulators, businesses, consumers) operating at different levels, with different priorities, insights, knowledge, and access to data. Each will have different perceptions on what the SOI actually is. Each will view the system, and related issues, through their own particular lenses.

Scope of this review

We focus on those regulatory systems established through statute in which government or its regulator plays a leading role (as opposed to similar systems, such as market self-regulation or those administered by professional bodies). We also largely draw on practices applied in Western democracies (with extra insights taken from other sectors and geographies).

Examples are typically drawn from critical infrastructure systems that protect communities; that provide essential services such as energy and water; and that connect communities via transport and communications networks. Importantly, we consider both the tangible and intangible (including digital, knowledge, and institutional) aspects of these systems. The types of complex issue and hence SOI we have in mind include:

- Reducing river or coastal pollution, which involves multiple interacting actors and regulators, social activism, and long-term implications from climate change uncertainties.[3]
- Responding to new autonomous technologies[4], such as the US Coastguard not currently having the clear authority to tackle varied demands and risks from autonomous shipping.[5]
- Application of various forms of AI, such as those developments that in effect lead to asset or network operators outsourcing data and control of parts of their

infrastructure to other systems or organisations over which they have no direct influence.

- Managing critical interdependencies between hitherto discrete systems that are themselves facing extensive and rapid change, such as water, energy, and communications.

In a separate but related ongoing review, we are considering the potential role of regulation in supporting resilience of critical infrastructures.[6] Enabling resilience offers another way of mitigating the impacts of complexity.

While the focus of this report is on regulation, many of the observations equally apply to governance systems. This could include, for example, those governance mechanisms that oversee those systemic actions needed to transform national infrastructure into a net zero enabling, resilience enhancing, sustainability supporting system.[7]

Methodology

The findings and material in this report draw on material generated through our previous research. Extra insights have been gained through a combination of desktop research, discussions with relevant international experts, two workshops (one of a general nature, the other focused on the implications of complexity for legal frameworks), and peer review as the report was developed.

Regulatory vulnerabilities

Today's regulatory systems already have vulnerabilities. These can be amplified by complexity. This subsection provides a brief overview.

When successfully designed and implemented, regulatory systems deliver important benefits to society and to businesses. There are many examples across the globe of good regulatory design protecting people from harm and supporting the integrity of critical social, natural, and physical infrastructures on which we all rely – indeed, there are so many positive examples that regulation is often taken for granted. Regulatory systems have contributed to achieving substantially cleaner air and water; safer food, work and travel; and improved social justice.

However, there are failures too – big and small – where serious negative impacts have been linked to the ineffective design or operation of a regulatory system. These can result in highly visible disasters; in long-term issues that may only emerge after decades; or in the 'silent killers' linked to chronic underperformance of regulation or to disproportionate barriers to beneficial innovation. In some cases, a relevant regulatory system may simply not exist.

In previous work [1], we identified several potential vulnerabilities within regulatory systems, exposed by regulatory failures to date.

These are summarised in Table 1.

Table 1: The vulnerabilities of regulatory systems (based on reference 1)

Power or scale imbalances	Politics, power, and vested interests can combine to create wealth/power loops, regulatory capture, corruption. Scale imbalances can lead to disproportionate impacts.
Lack of cognitive diversity	Can limit the creativity and injection of new ideas needed to respond to complex or uncertain conditions.
Long-term or latent issues	Today's urgent problems tend to divert attention from, and thwart efforts to address, the bigger problems of tomorrow.
Regulatory boundaries	Regulatory changes or multiple regulators can create gaps, inconsistencies, or unclear cross-boundary accountabilities.
Failure to learn or spot issues	Organisational cultures and closed mindsets can lead to missed warning signals (including from lone voices).
Knowledge gaps and asymmetries	Industry and regulator asymmetries can result in inappropriate responses (too cautious, too insular, too trusting).
Institutional inertia	Can lead to long-established organisations continuing with deeply embedded procedures, even when well out of date.

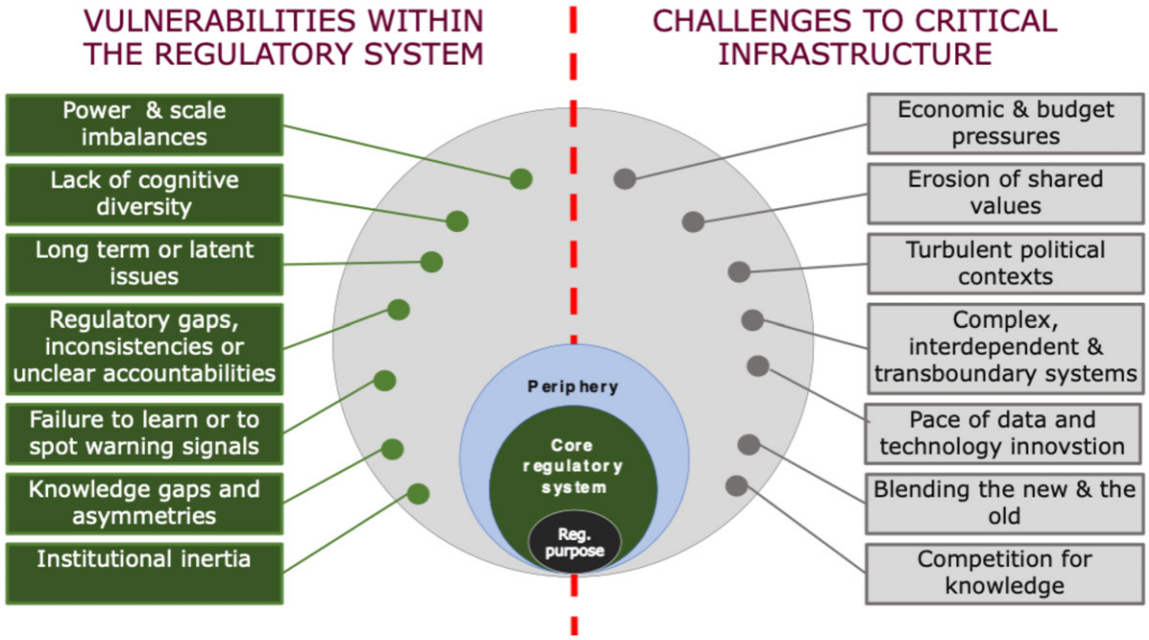
Implications of complexity

Today's regulators and policymakers face issues vastly different to what they are used to – in levels of uncertainty and ambiguity, in scale, in pace of decision-making, and in the polarisation of competing values. Rapidly changing technological and societal developments, together with resource constraints, are bringing both positive innovations and multi-dimensional risks to lives and livelihoods across the globe. This section sets out some of the implications.

Factors tipping towards complexity arise from multiple interactions across multiple actors and highly interconnected systems (often in unexpected or unrecognised ways). The implications of associated emergent behaviours is that long established, and previously successful regulatory practices can be undermined. There are already many existing regulatory vulnerabilities that should be addressed but all too often are not. Complexity amplifies the challenges they pose and can combine to create a compounding crisis (Figure 1).

High levels of interconnectivity also give rise to the unprecedented scale, multidimensional and interdependent nature of the systemic risks we face.

Figure 1: Emerging trends can amplify and compound existing vulnerabilities[1]



As a practical example of multidimensional risks, a lightning strike that triggered a UK power outage in August 2019[8] shows how risks can propagate across interconnected, interdependent systems. The technical response in the transmission network worked as intended and led to over one million customers being disconnected for about 45 minutes. Impacts in most other sectors were quickly resolved (transport, water distribution, oil refinery, and hospital systems). But on the railways the outages tripped control systems on 60 commuter trains, half of which required a technician to attend in person to restart them. This led to 23 train evacuations, 371 cancellations, and major London stations closing for several hours due to overcrowding at 5.00pm on a Friday. This rail chaos was the main source of public anger, attracting media and parliamentary scrutiny.

Other examples, showing how risks can cross social, natural, and physical boundaries, include the scale and speed of growth of invasive species such as zebra mussels in the Great Lakes that led to power plants becoming inoperable;[9] or how social media is leading to fragmentation of societal and intergenerational values, playing out in political elections as well as public trust and attitudes to regulation or institutions. Issues of trust are compounded by issues such as 'deep fakes', where AI manipulation of video and audio material creates convincing disinformation.

In addition, regulatory questions and issues that might previously have been considered as technical or national challenges can now have much wider transnational

implications, with immense direct and indirect costs should associated risks crystallise. The rapid development and deployment of drones illustrates this point:

- At technical and national level, drones are already demonstrating their potential to deliver substantial societal benefits by sending medicines to remote locations, monitoring critical infrastructure, or supporting crime prevention. The use of drones introduces risks that extend existing legislative and regulatory frameworks, and studies are underway to support this beneficial innovation by understanding and addressing related questions.[10]
- A geopolitical perspective highlights the potential for drones to trigger a global polycrisis (the simultaneous occurrence and interaction of several catastrophic events). The sudden cost-effectiveness, accessibility, and potency of swarmed unmanned aerial weapons increases the threat of military conflict by actors previously unable to access the means – a threat that has materialised in recent conflicts.[11] Drones are therefore catalysing potential rearrangement of the global order.[12] In addition, global technology companies may control, and can thus 'switch off', satellite links on which drones may depend: illustrating another form of power shift.

Challenges of complexity

To explore where and how regulation might evolve to be fit-for-complexity, we focus on five critical attributes. Complexity can be described in many ways, making it difficult to identify. However, in practice, the presence of several of these attributes provides a strong likelihood of complexity.

These five critical attributes were derived from a combination of previous research (including the vulnerabilities set out above) and insights gained through workshop discussions. For each, we identify challenges and potential implications for regulatory responses. The five areas are:

1 **Unpredictable cause and effect:** relationships and interactions across highly interconnected systems are ambiguous, emergent, and dynamic, making them unpredictable. That can undermine accountability, regulatory enforcement, and the ability to apply credible controls.

2 **Misaligned boundaries:** regulation typically targets specific activities or sectors. Multidimensional risks, enabled by digital platforms, can make traditional boundaries irrelevant.

3 **Disruptive innovation:** by its nature brings extensive uncertainty, often with significant information asymmetries (e.g. between innovators and regulators) and/or competing interests.

4 **Mismatched time frames:** the nonlinear pace of technological developments can leave bureaucratic regulatory systems behind. There are added challenges from obsolescence, or of old and new regimes operating simultaneously within different paradigms.

5 **Societal confidence:** how do regulators retain a public 'licence to operate' and trust in the face of societal and/or political polarisation?

These five attributes are not mutually exclusive. Despite the challenges they present to current regulatory systems, it is equally important to remember that disruptive technologies and business models also bring an infusion of new ideas and capabilities that can spark regulatory innovation, as well as potentially address the global systemic challenges the world now faces.

1. Unpredictable cause and effect

Today's increasingly complex infrastructures are dependent on intangible digital networks and data flows that connect us to one another, to ideas, and to institutions in ways that are unprecedented in scope and configuration. Extensive interconnectedness leads to system behaviours that are dynamic, and therefore changing; emergent (developing 'bottom up'); unpredictable; and only understandable in retrospect (if at all).

The associated ambiguities are a significant characteristic of complexity and make it difficult to determine cause and effect with any degree of confidence. This raises specific challenges:

- The involvement of multiple interacting actors within a SOI is likely to blur accountabilities, making enforcement challenging, and thwarting 'ownership' of the risks that might otherwise encourage individual initiative and leadership of actions that support harm prevention. It undermines existing regulatory practices that rely on clear definition of a 'dutyholder' (person or organisation accountable). A recent analysis of the 1997 Bexley train derailment illustrates the issues.[13]
- Demonstration of causation (as cause-in-fact or proximate causation) is a fundamental requirement of tort and criminal law. For example, if harm only arose from the independent actions of multiple interacting entities and would not have occurred but for the action of all of them, then how could routinely applied concepts such as 'polluter pays' be enforced without any confidence about who had created the harm? If regulators are unable to attribute harms, their ability to enforce statutory requirements is undermined and effectiveness diminished by the absence of credible sanctions.

Photo: Alamy

The 1997 Bexley derailment highlights practical and legal issues of a system that relies on multiple interconnected actors that operate largely independently, and the difficulty of applying criminal or civil law to complex systems.[13]

- When risks crystallise, understanding how, when, or where to inject some form of control or how to prevent escalating, cascading, or compounding risks beyond the system boundaries is critical. This relies on a better appreciation of what lies beyond perceived boundaries[2], and consideration of the nature of the interdependencies involved.[14]

There are also fundamental tensions between the unpredictability associated with complexity and the predictability needed by the laws (and formal rules) underpinning regulation. For example, laws are by their very nature general, impartial, and nondiscriminatory in application. That makes it difficult to accommodate the unexpected and the exceptional (that were initially rare but become increasingly common with complex systems). In addition, it should be possible for those governed by the laws to anticipate the consequences of noncompliance. That need for predictability makes it difficult to adapt, evolve, and correct laws and rules when they counter precedents and locked-in interpretations. In short, the generic characteristics of laws (general, impartial, predictable, framed by precedent) do not mesh well with a world of increasing uncertainty and complexity.

Possible implications

One practical response may simply see 'hard powers' (such as formal rules, enforcement) used in much more specific, targeted ways, and increased emphasis given to the 'soft powers' that are also available to regulators (for example, influence, coalitions, data sharing, informal standards such as the UK government-backed 'cyber essentials' standards[15]). There are also more generic expectations around the behaviour and competence of directors under company law that could be reinforced (either directly or through reputational levers).

More specific responses include evolution of legal frameworks to bound the issues or to introduce established tools (such as transparency) to shape behaviours. These options can work well on a short-term or interim basis, but need vigilance and ongoing review to ensure their continuing validity as the SOI changes and credible limits of these mechanisms are approached.

There are also temporal aspects to these types of response. For example, digital systems can create a de-facto standard by embedding themselves into wider applications or systems. In effect, they can secure a lock-in before any issues materialise and constrain future regulatory options.

Clarifying accountability: the regulatory and legal ability to hold people to account relies on clarity, and ideally this can be linked into existing legislative structures. Achieving clear legal definitions, with coherent alignment between logical engineering interfaces and risk ownership, is far from straightforward for a system with multiple interfaces.[16]

By way of example, the UK Law Commissions recently recommended legal reforms to ensure unambiguous accountability for self-driving vehicles[17] and for remote driving on public roads (where the remote driver may be far from the vehicle).[18] These include new definitions, such as:

- the person in the driving seat becomes a 'user-in-charge', with immunity from a wide range of offences that arise directly from the driving task
- an 'Authorised Self-Driving Entity' (gets the vehicle authorised) that is responsible and subject to potential regulatory sanctions if the vehicle drives in criminal or unsafe ways
- an 'Authorised Entity for Remote Driving Operation' is responsible for maintaining safety in areas beyond a remote driver's knowledge or control (not the individual remote driver).

A proposed response, worth exploring further, is the extent to which the concept of 'joint and several liability' (widely applied in commercial law) could be applied in the legal frameworks underpinning regulation. Joint and several is when two or more defendants acting in concert or independently cause harm, and the resulting damage cannot be allocated to a particular defendant. Each defendant is severally and fully responsible for the entirety of the harm, even though all defendants are jointly responsible for it. The entire judgment may then be collected from any of the defendants found responsible, unless a court finds that different amounts of negligence of each defendant contributed to the harm. This would still rely on an ability to characterise the accountable entities within a system, and for the expectation of liability to be meaningful, if this was intended as a deterrence to poor behaviours. However, a problem with joint and several liability in the context of complexity could be that liability falls on those with deep and available funds, such as municipal and public coffers, so that benefits are privatised and any losses socialised.

Bounding the problem: through legislation to constrain risk potential. This legislation could take different forms. For example, in the case of remote driving, the issue of enforcement across international borders was addressed through a recommendation that remote driving from abroad should be banned until international agreements are in place to provide appropriate enforcement. In essence explicitly recognising regulatory limits and removing ambiguity where it could credibly do so.

As a more extreme example, the 'lockdowns' implemented in many jurisdictions worldwide to contain the spread of COVID-19 shows how draconian action can be used to introduce firebreaks that limit escalation of a specific issue. There are, however, downsides from such measures as control of one specific risk can result in other equally serious ramifications emerging elsewhere.

Transparency: to encourage the 'right' behaviours from actors in complex systems and to provide information that could be of value in retrospective analysis of a failure. Examples include potential requirements for AI developers to identify training data for their systems or to watermark AI generated material. The 'duty of candour' is already a feature of health regulation and is being extended into other sectors.

Notwithstanding these developments, significant barriers can still be created by the subjective perspectives and motivations of the actors in the system (whether individuals, organisations, or institutions) or by commercial realities such as protecting data ownership or intellectual property. This may lead to information being concealed (deliberately or subconsciously) through tactics such as denial, dismissal, diversion, or displacement (potentially to avoid responsibility, embarrassment, or liability). Such behaviours led to the wrongful prosecutions of thousands of subpostmasters in the UK, enabled by a combination of the widely held 'computer never lies' mentality and the ability within the organisations involved to conceal the serious issues of data unreliability.[19]

It has also been suggested that regulation could be used to require data collection along the lines of an aircraft flight recorder ('black box') and/ or an auditable record of decision-making to inform failure investigations and, potentially, to hold people to account. This might address, for example, ambitions for an autonomous vehicle to be able to 'explain' decisions that it took[20] as a fundamental component of in-use regulation to be able to learn from incidents. This concept has demonstrated its worth in improving transport safety but may prove disproportionately demanding for the more complex systems with extensive interconnections. It may not, however, address the underlying issue of indeterminate causality.

2. Misaligned boundaries

Boundaries pose a major problem. Regulator mandates and regulatory activities are bounded, but complex SOI rarely have obvious boundaries. That can lead to misalignment.

Regulatory mandates defined through legislation confer the legitimacy needed for regulators to fulfil their functions. Where multiple regulators have a mandate linked to a SOI, then regulatory inconsistencies, gaps, or unclear accountabilities make it harder to enforce rules and create scope for regulation to be 'gamed'. Issues often only become evident in the aftermath of tragedy or in business innovations that bypass intended controls. In addition, critical overlaps and interdependencies might evolve over time between what were once discrete SOIs, for example water, energy, and communications.

Dynamic and unpredictable behaviours linked to complexity also heighten the likelihood and impact of misalignments between regulatory systems and the SOI:

- Increased likelihood because the boundaries of a complex SOI are not obvious and can change over time. Information or resource flows between what is thought of as 'inside' and 'outside' that system, or introduction of new technologies, can mean that many systems that are not initially envisaged as complex can become so. As interconnections grow, what starts as discrete and well bounded can become part of some broader 'system of systems'; or its components may form part of multiple systems, simultaneously. Misalignments can develop unnoticed between the SOI and related regulatory systems.
- Greater impact because a desire to reduce a problem to manageable proportions can lead to an SOI being defined less by its actual purpose (or problem to be solved), and more by its physical, organisational, or geographic domains at a specific point in time. This can obscure the actual issues at play.[21] Unseen, and therefore unrecognised factors affecting the regulatory system might lie beyond perceived boundaries and could prove to be even more important than those on the regulatory radar.

  For example, nutrient and other river pollution comes from farmers, water companies, and houses, exacerbated by roads and other infrastructure run-off, and poor flood defences. Cost-effective reduction in river pollution comes from a combination of these contributing to reducing their effects. Notwithstanding specific initiatives to take more of a catchment approach (such as the Wye Catchment Partnership[22]), current regulatory boundaries and approaches do not adequately reflect that this is best done in a catchment planning context.[23]
- Greater impact because highly interconnected systems can bring in even more stakeholder perspectives and behaviours, with differing terminologies and competing (but legitimate) views on the issues at play. With few (if any) able to describe the entirety of the SOI, partial views can lead to regulatory designs that embed conflicting objectives and drive unintended behaviours. This is also seen, for example, in how different regulators focus on performance linked to specific assets or discrete physical networks, while governments or intended beneficiaries of regulation may be more focused on the overall functional performance experienced.

Photo: Alamy

Tackling river pollution is made complex by crossing multiple regulatory boundaries: pollution comes from farmers, water companies and houses, exacerbated by roads and infrastructure run-off, and flood defences.[23]

Possible implications

The crucial importance of remaining aware of what happens beyond the porous boundary of a complex system and options for achieving this were explored within a previous case study.[2]

Flexibility of mandates: a regulator's mandate and legitimacy is grounded in legislation or statements by government, its agencies, or the courts. This can be achieved with varying levels of stability and predictability through a combination of primary legislation and standards and/or rules set through secondary or local regulations (rules). Common law (derived from custom and judicial precedent) allows evolution of legal principles that take account of societal norms. However, these legal changes are invariably developed reactively in response to an issue that has already emerged.

Regulatory mandates are designed, and design choices are highly contextual. If definitions are too tight, it can hinder agility and leave the system less able to deal with complexity and changing boundaries. Conversely, if the mandate is too loose, it can introduce ambiguity and raise questions about regulator over-reach. The tension is illustrated by the US Supreme Court's use of the major

questions doctrine for new rules deemed to have high economic and political significance. Under this body of law, to satisfy both separation of powers principles and a practical understanding of legislative intent, the agency must point to "clear congressional authorisation" for the authority it claims.[24] Failing that, the Court will strike it down.

This has resulted, for example, in veto of plans by the US Occupational Safety and Health Administration (OSHA) to require COVID-19 vaccination in workplaces and the inability of the US Environmental Protection Agency (EPA) to regulate emissions from power plants. The major questions doctrine has profound implications for regulatory agility in the face of rapidly changing contexts.

Oversight bodies: mismatches between regulatory boundaries and the SOI drive a need for clarity on who is tasked with a whole-of-system overview of issues that cross regulatory boundaries. These cross-cutting issues also need mechanisms to resolve trade-offs (such as between cybersecurity and safety; efficiency and resilience; or short- and long-term focus) and to secure key data flows and interactions. This can be achieved through agencies operating at a more strategic level, advising or challenging governments on complex, cross-cutting issues.

The independent Delta Commissioner in the Netherlands provides one example.[25] They have a statutory remit to oversee and connect the multiple governmental layers and stakeholders involved in addressing future risks to floods and freshwater supplies. The Commissioner is required to take a systems perspective that ensures cohesion between the Delta Programme's component parts and connects short-term decisions to long-term goals. The Commissioner does not have formal decision-making authorities, but instead relies on influence through their powers to bring about, enable, and catalyse stakeholder actions; to report directly to parliament; and to draft the yearly investment programme (averaging €1.25 bn/year until 2032). It is important to note that the Commissioner does not operate in isolation but is an integral part of a comprehensive governance structure that is designed to support planned adaptive regulation.[23]

Surfacing unknown knowns: regulators need to remain vigilant to risks emerging from across a complex SOI and beyond its immediate boundaries. This requires input from diverse and distributed communities to gather and share insights on what is happening in practice. Additionally, being alert to emerging issues is necessary but insufficient on its own: specific mechanisms also need to be established to ensure any observations of abnormal behaviours are acted upon.

This is easier said than done. Disciplinary silos and different terminologies can hinder collaborative work, and need addressing head-on. This includes, for example, establishing safeguards to mitigate pitfalls such as cognitive bias (which may manifest itself as being dismissive of nonexperts, or being unwilling to listen to those challenging the status quo). There are many disasters where subsequent investigations showed that risks were known but not acted upon, and that the concerns of people directly involved were not adequately listened to. The 2017 fire that engulfed the high-rise Grenfell Tower in London, leading to the loss of 72 lives, is one example. Here, a culture that undermined fire safety became progressively worse as systemic failings in regulatory design and implementation created scope for shortcuts and noncompliance, with trust in the institutions involved being increasingly eroded as residents' voices were ignored.[26, 27]

3. Disruptive innovation

Disruptive technologies and business models enabled by technology are bringing both substantial benefits and significant risks to society.

The opportunities include enhancing our ability to tackle global issues such as productivity and resource efficiency; health issues; and climate change. The risks can come both from deployment of the technology itself, and from the fundamentally altered regulatory contexts this creates. For example, disruptive changes enabled by the technologies and global data networks of the information age have reconfigured power bases, fundamentally changed business models and re-set societal dynamics. In many cases, innovation will come from the convergence of previously distinct knowledge bases or technologies and can therefore be deployed at previously unimagined pace. This pace adds to the challenge for regulators.

There are equally many positive opportunities for regulators to make the most of emerging technologies, for example through better use of data and the insight this can bring.

From a legal and regulatory perspective, disruptive innovation raises issues such as:

- **Under-appreciation of the uncertainties and realities of multidimensional risks:** tackling a risk in one domain may simply lead to another risk emerging elsewhere. As an example of unforeseen and unintended consequences, modified security controls at airports, and changed passenger behaviours after the 9/11 terrorist attacks in the US led to a switch from air to road use. That resulted in an estimated 1,595 extra deaths nationwide the following year due to road traffic accidents.
- **Delays in decision-making due to uncertainty:** competing but legitimate perspectives on the uncertainties involved in a complex system can thwart action if the trade-offs needed for optimal responses remain unresolved, and particularly where there is impetus to collect more data (which could, in any case, rapidly become irrelevant in a volatile or dynamic system). Defaulting to 'do nothing' can bring its own risks and costs.
- **Knowledge asymmetries between regulators and industry:** issues can arise when regulators struggle to keep up with innovation and industry expertise. The underlying causes include: industry's greater ability to fund, attract, and invest in people; intellectual property rights meaning that many technological aspects remain proprietary to the companies that develop them; and limited public access to critical data and knowledge held by the private sector (which can be further complicated by over-sensitivities to the data protection laws that now apply in many countries).
- **Power imbalances within markets:** these can arise from large organisations (including technology and social media companies) being in a position to establish operating norms, set default standards, and control access to valuable data (or even suppress data that shows negative impacts). This can consolidate market positions, create barriers to entry and/or lead to regulatory capture (when the influence gained by regulated industries over their regulator, either directly or indirectly, leads to the regulator supporting industry instead of serving the public interest).
- **Challenges to the very foundational definitions that underlie regulatory regimes and social norms:** in the life sciences, for example, innovations around in vitro fertilisation began to change the definition of an embryo. Together with increased ability to access and manipulate ex vivo embryos, this led to wholescale revisiting of the definition of a 'person' (morally and legally) and invited re-evaluation of kinship relationships (genetic, gestational, contractual, state-ordered). Similar challenges are now being seen with gene editing, cloning.

  Comparable questions are being raised by autonomous vehicles regarding the definitions of a 'driver'. When foundational definitions are up for debate, they re-introduce the question of the purposes served by the definitions, which inevitably leads to a policy debate – and ambiguity until it has been resolved.

Photo: Alamy

Disruptive technology can require re-evaluation, and re-open debates, about foundational definitions, such as 'who/what is a driver' for an autonomous system.

Possible implications

Explicit recognition and communication of uncertainty is a starting point. There needs to be an appreciation of when limits of knowledge or regulatory approaches are being reached.

Precaution: there are competing views on how innovation should be dealt with in regulatory design, as highlighted by current debates on the regulation of AI. For some, regulation plays an important role in allowing society to

exercise control over unconstrained developments and to respond to concerns that an unbridled pace of innovation is not always beneficial. For others, innovators should be left free to experiment as they see fit with new technologies and business models – a world of 'permissionless innovation'[28] where you ask for forgiveness when things go wrong.

In these circumstances, people may seek to invoke a 'precautionary principle'. In practice, this principle is highly contextual and has shown varying degrees of success (or, depending on perspective, varying degrees of failure, because of the resultant inappropriate decisions). Application of a precautionary principle across different countries and at different times has been highly context-specific, variegated and inconsistent.[29] Precaution can be strong (cannot do it unless proved safe) or weak (can do it if no evidence of harms). In complex contexts the real (and more useful) question is how to deal with multiple risks and alternative actions. Optimising the trade-offs between the risks of inaction (harms being exacerbated) and the risks of action (costs, inhibited innovation) will not be straightforward.

Independent knowledge / observatories: knowledge asymmetries have traditionally been addressed through regulators drawing on independent technical or research expertise to inform decision-making on specific topics. As risks become even more multidimensional and global, this is likely to be less effective, and ways of accessing independent views are evolving in response. Post-normal science, for example. proposes extending a typical scientific peer community with extra views, to co-produce better quality knowledge for decision-making (and build trust) on issues such as climate change, where facts are uncertain, values in dispute, stakes high and decisions urgent.[30] This could involve engaging interested individuals from outside established institutions, who may not have what is seen as the 'usual' professional or academic background. Getting value from such mechanisms will require substantial investment in 'decision science' capabilities [31] and in overcoming the different disciplinary languages that can get in the way of collaborative work.

Also, "wisdom of crowds" [32] approaches rely on independent perspectives: care is needed to avoid migration towards interdependence and groupthink over time.

The adoption of AI tools across all sectors of the UK economy has significant implications for regulators. A proposal for a shared, collaborative capability for regulators, hosted, and convened by a politically independent and technically authoritative body, responds to the issue of increasingly visible knowledge asymmetries.[33] As part of advancing AI readiness, this hub would draw on multidisciplinary knowledge and international expertise to track and horizon scan global developments. Comparable proposals made by others noted that "effective regulation and control is and will likely remain an ongoing research problem, requiring an unusually close combination of research and regulation." [34] The issue of independence is critical: will such a body be hosted or heavily sponsored by one of the large technology giants, or will it truly remain in the open, public domain?

The European Commission has sought to deal with knowledge asymmetries by designating online platforms with more than 45 million users as 'Very Large Online Platforms' (VLOPs). The VLOPs designation triggers more stringent and targeted rules designed to tackle particular risks that come with digital market dominance, such as illegal content, impact on fundamental rights, public security, and wellbeing.[35]

Adaptive approaches: adaptive models are used in both regulatory and governance systems as a way of dealing with the deep uncertainties of complex systems or innovations. Adaptive regulation takes many different forms, with a defining characteristic being that it is explicitly designed to allow for changes in regulatory policies or rules over time as new evidence and knowledge emerges. Examples spanning different sectors, nations, and cultures demonstrate that adaptive methods can be successfully applied in many ways and many different contexts.[36]

Adaptive methods will not always be suitable: the benefits of a stable regulatory system may outweigh the value or cost of adaptive models. There are practical issues, such as determining: the frequency of review (frequent changes or stability, predictability); scope of impact assessments (light touch or more comprehensive, at greater cost); mechanisms for decision-making (rapid and automated or deliberative and discretionary). Experience has shown that moving from the compelling concept of adaptive regulation to practical reality brings many implementation challenges, not least of which is tackling entrenched mindsets and culture. It also relies on trust.

Different forms of regulation design can also affect adaptability. For example, defining "general duties" (like those general duties on UK employers "to ensure, so far as is reasonably practicable, the health, safety and welfare at work of all their employees" [37]) creates more flexibility in how that is achieved, options for resetting expectations and hence enables adaptation. (It also raises the question of how to define a 'dutyholder' in a complex system, as described in the previous section). However, the use of general duties ('outcome or goal-based regulation') as an alternative to rules ('prescriptive regulation') also relies on broader factors such as the local political and legislative frameworks; societal attitudes (for example, to compliance), maturity of the system; regulator capacity, capability, and resources. In practice, a hybrid design will often blend elements of both prescriptive and goal-based approaches, and that hybrid form can equally be applied to adaptive designs.

Polycentric governance: the underlying concept of a 'regulatory system' aligns with models of polycentricity, in that many tasks to shape behaviours and influence regulatory outcomes can be carried out by many decision centres of many different types. This includes government (through its network of public agencies) and private, professional, or voluntary and community-based organisations (each of which may be composed of multiple parts).

Polycentric governance covers a system in which many diverse centres of partial authority collectively cover the full range of governance (or regulatory) tasks.[38] The model, derived from responses to deal with 'commons' issues, emphasises a situation in which mechanisms conducive to information sharing between the various parties involved improve the potential for self-organisation and prompt adaptive response to changing signals in complex systems; as well as sanction and enforcement at multiple levels carried out by the users.

In this context, the role of a regulator is to provide an overall direction and framework for nested decision-making groups to work within. This has parallels with the concept of a regulator using their soft powers to catalyse and provide leadership for mission-oriented policies: defined as systemic public policies that draw on frontier knowledge to attain specific goals or big science deployed to meet big problems. Missions provide a solution, an opportunity, and an approach to address the numerous challenges that people face in their daily lives.[39] An obvious risk is that fragmentation of decision-making leads to a fractured regulatory system, which highlights the importance of aligned objectives and incentives for those involved.

Models that draw on polycentric concepts have been proposed for addressing complexity [40] and for tackling governance of the Internet of Things (IoT) – a highly dynamic system, which brings both massive sociotechnical potential and significant threats, such as cybersecurity.[41] A distinctive feature of the latter proposal is the integration of a network of operational experts into the regulatory systems, bringing their much more dynamic management procedures to regulate system behaviours while sharing aligned incentives. These individuals bring deep practical experience to manage day-to-day IoT security, and they offer centralised regulatory bodies a mechanism for keeping pace with emerging risks and uncertainties.

Comparable models have been explored as a way of solving complex socio-environmental problems and improving social stability in Latin America through distributed solutions led by social innovators. Empowering 'problem detectors-solvers' alongside current 'top down' efforts appears to be a feasible way of complementing current efforts from governments, enterprises, multilateral organisations and NGOs.[42]

4. Mismatched time frames

There is a temporal aspect to complex systems that is unaligned with the discrete and relatively static entities that have been traditionally regulated. The inherent time lag between cause and effect affects the dynamics of the system and is a potential source of stability[43] or of early warning signals – but it can and will change over time. The time frames over which system behaviours are viewed, the influence that time and rates of information flows have on interactions across the system, and the multiple states that may exist concurrently all add to the complexity.

- We face both acute (that is, severe or intense) risks and chronic (that is long term) risks. Small events can scale at extraordinary pace: a cluster of pneumonia-like symptoms in Wuhan City escalated to WHO declaring the global COVID-19 pandemic in about 12 weeks. Alongside these, high impact events widely predicted by experts (but that attracted low public or political urgency) are increasingly visible: the fires, floods, and heatwaves seen around the globe, attributed to climate change. As chronic risks materialise, they can themselves trigger rapidly escalating acute events.
- Many of the trends we see around us reflect a transition from the industrial to the information age, and the emergence of cyber–physical systems that blend tangible and intangible elements. In this transition, like many before, 'old orthodoxies are dying, new ones have not yet been born, and very few things seem to make sense.'[44]
- Geopolitical and global aspects of regulatory complexity: each jurisdiction (whether federal like the US, quasi-federal like the EU, or unitary like many nations) will have its own policy imperatives, and divergence will be inevitable. The challenge of the speed differential between technology and law/policy will therefore be compounded by cross-border differentials in both the speed of political response (reflecting national priorities) and the substantive policies chosen to address emerging risks (reflecting national contexts). These divergences were clearly evident, for example, during COVID-19. They can offer advantages if viewed through the lens of 'experimentation' and learning from others.

Photo: Alamy

Timing is crucial: there is typically a window of opportunity before digital systems have an established presence and lock themselves in by becoming the de facto standard.

Importantly, regulatory systems are highly contextual and dynamic, shaped by their history and by external factors such as political contexts and influences that are themselves changing.

Possible implications

Short and fast feedback: governments typically prioritise short-term goals and interests over those of a longer-term nature. Nongovernment organisations, and campaigning bodies, can mitigate this to some extent through their activities if they can garner strong public support on long-term issues – where voters go, politics will often follow, although this can also bring the risk of prioritising populist views as opposed to necessary actions.

A generally reactive approach to regulation tends to respond with greater urgency to acute as opposed to chronic issues (even where the latter may have more significant overall impacts). This happens for several reasons that include a human bias towards the present, the deeper uncertainties of longer-term futures and electoral cycles. Those in the driving seat tend to focus on the fast variables which can be monetised or bring immediate political benefit, with little recognition of the consequences for the slow variables, such as environmental and social factors which might have more profound systemic implications.

The use of 'regulatory sandboxes' (in which regulatory rules are relaxed on an interim basis to allow innovations to be tested and assessed) and other forms of experimentation have been shown to be a useful mechanism for assessing innovations.[45] This experimentation has many benefits. However, when adopting new regulatory designs and rules based on the outputs, it is essential to remain mindful of both short and longer-term feedback cycles, and vigilant to new but unexpected behaviours. Like Hemingway's bankrupt, catastrophe often happens in two ways – gradually and then suddenly.

Institutional inertia: the pace of technological development we see around us today is much shorter than the lead time required for developing a regulatory or legal response, particularly if entirely new statutes or act of parliament are needed.

For example, foundation models began to emerge in 2018 as a way of building AI systems – five years later they are being widely deployed. These models involve training one 'foundation' model on a huge amount of data (such as BERT, DALL-E, GPT-3) and then adapting it to many applications (for example, in law, healthcare, engineering).

A review [46] of associated opportunities and risks observed that despite their impressive performance, these foundation models can fail unexpectedly, can include biases and are still poorly understood. In addition, the homogenisation that is enabling their widespread global application at scale creates systemic risks: defects in the foundation model are inherited by all adapted models downstream.

From a regulatory perspective, there is an important window of opportunity to shape governance approaches that exists during the development phase (in the period from concept to early deployment). Once there is widespread deployment, issues become much harder, or even impossible to deal with. By the time harms linked to foundation models become visible, foundation models that could include years of subtly flawed training data may already be deeply and irreversibly woven into our societal infrastructure. Mitigation is likely to be through mechanisms and research networks that support early recognition of new technologies and their potential ramifications. Even with those, it is likely that any responses would need to draw on alternatives to formal laws and rules that typically take several years to develop.

Transition: history shows how uncertainty and recognised ignorance tend to increase drastically during periods of major transition, with complexity, chaos, and contradictions as dominant themes. There is a need to remain aware, and alert to, the specific vulnerabilities that exist in the interfaces between the old and new states.

As noted in a previous section, a power outage triggered by a lightning strike in August 2019 cascaded to other infrastructure sectors and led to a significant disruption of essential rail services.

As well as vividly illustrating critical interdependencies, reviews of the incident highlighted mismatches between the operational practices, software, and design codes developed for largely centralised electricity generation and those needed by an increasingly distributed network.[6] An electricity transmission network that used 'rules' to control what might otherwise be complex, shifted back to complexity as those rules became invalidated by the introduction of new technologies. This could readily happen in other sectors and domains. Complexity is compounded by the transition itself and the need to blend fundamentally different innovative technologies with legacy systems and processes, that have often not been well maintained.

Obsolescence: the deeper challenge we face in regulating complexity may lie not in the new ideas or methods, but in recognising when the old ones are no longer relevant. Knowledge that has long served us well can become obsolete and lethal. Regulators can become irrelevant. Yet it can be difficult to remove either from the statute books. Routinely reviewing the relevance and coherence of existing statutory requirements and regulatory bodies remains a vital part of preventing the unplanned accumulation of laws and related demands on businesses and public services.

This is not new. In 1972, Lord Robens reviewed UK occupational safety and health laws.[47] He cautioned against expecting better performance from an ever-expanding body of rules enforced by an ever-increasing army of inspectors: "The first and perhaps most fundamental defect of the statutory system is simply that there is too much law. … has an unfortunate and all-pervading psychological effect … The primary responsibility for doing something about the present levels of occupational accidents and disease lies with those who create the risks and those who work with them." With the growing abstraction inherent in complex systems, this responsibility for ownership of risk can be easily circumvented, falling on to the insurer of last resort, government itself.

5. Societal confidence

Public confidence and trust (a regulator's 'licence to operate') is an essential lubricant of regulatory systems. Political, economic, and societal contexts create three strongly interrelated challenges:

- Geopolitical turbulence can heighten tensions between technologies operating at the global level and the geopolitics that influences individual markets – seen, for example, between the US and China and the impacts on the adoption of their technologies.
  This can reinforce populism and influence attitudes on deeply value laden global issues such as climate change or technology. Regulatory systems may struggle to keep up and be overtaken by events.
- Across much of the world, trust in governments and institutions is at an all-time low, with many doubting their ability to deal with the challenges we face.[48] 24/7 news channels and social media can fuel conflicting views between generations, or between experts and the more sceptical population. Differing attitudes to privacy and surveillance also affect public trust.
  While the different perspectives may all be legitimate, erosion of shared values and fragmented societies can reinforce inequalities. The gaps in cohesion can then undermine credibility and, by further weakening trust in institutions, can undermine a regulator's public licence to operate.
- Economic, budget, and resource pressures are likely to rebalance views on the trade-offs between precaution, innovation, and resilience. It will add to demands for regulatory systems to become ever more efficient and supportive of innovation. Tightening of funding and resources for regulatory innovation also raise questions over who will pay for investments needed and the acceptability of introducing significant change to regulatory systems.

Image: SocietyInside

Trust is an essential lubricant of regulation: supporting a public license to operate, diverse insights, and lower transaction

Possible implications

Licence to operate: regulation is generally associated with controls to manage the risk of harm to consumers, workers, the environment, or society more generally; to promote economic efficiency and growth; or to ensure common standards that create a level playing field for competing businesses and enable economies of scale. In a democracy, regulatory outcomes will ultimately have to be something that the public accept as fair and see as being in the public interest. If that is missing, the regulatory system collapses. A big question should always be 'how does the public view this'?

There is generally an implicit public expectation in the effectiveness of the regulatory systems and associated institutions that allow people to get on with their lives, confident in the belief that risk of harm to people and the environment is managed, and that complex values and ethical trade-offs have been resolved in the wider public interest. Issues arise when the regulatory system is visibly not working well or is at odds with what the public views as 'fair'. Concerns about regulation can then take a higher profile, diminish public trust and reduce a regulator's 'licence to operate'.

Similarly, the public may not tolerate a situation that conflicts with general notions of 'fairness' or where technologies are unleashed on them unchecked. And where sufficient voters think business behaviours are unsafe or unfair, then politicians and regulators are bound to follow.

Values alignment: many of the biggest issues and risks that society faces span system boundaries, have complex externalities, and bring many competing world-views and conflicting values that are challenging to capture. Choices and trade-offs in regulatory policies and resource allocation are deeply value laden and influenced by political contexts. This also influences aspects such as choices of 'leading indicators' to track when monitoring performance of a SOI.

Research and ongoing debate alongside technological developments such as AI is seeking to ensure those algorithms actually implemented into real-world systems are safe, that unsafe systems where goals are mis-specified are not deployed, and that mechanisms are embedded to ensure design errors are corrected once the technology is deployed.[48, 49] In reality, however, technical solutions will not be sufficient to ensure safety – and safety is not the only issue that matters to society. The inhuman speed of digital disruptions coming from automation, AI, and robotics could threaten our capacity to adapt, creating inequity, and potential economic harms to a large proportion of society.[50] Extra sociotechnical measures and institutions will be needed.

Societal trust: has long been recognised as a key element of regulation. Without trust, regulation becomes difficult to enforce [51] and that can lead to wider social

disorder. Trust directly affects willingness to share insights or data; to engage with adaptive approaches; to consider longer term intergenerational issues; and so on. It is an essential lubricant of the regulatory system.

Recent research [52] sets out the drivers of trust and distrust on the governance of significant technological innovations (such as AI, nanotechnology, gene editing). It recognises trust as an outcome that is based on perceptions of the trustworthiness of others. It highlights the importance of factors such as regulators being more open, visible, and showing positive impact, demonstrably focusing on the public interest(s) (not ideologies), and getting good at ethics, values, and stakeholder and citizen involvement.

The impacts of eroded trust go well beyond regulatory systems and can, ultimately, undermine governments. For this reason, damaging trust in the institutions and knowledge bases underpinning regulation (or other government policies) can be an end goal of attacks by terrorists or nation states. Fake news and cyberattacks are examples of this.

What has been successful in the past is often seen as a blueprint for the future. While there clearly are lessons to learn (and to relearn) from history, previously successful practices may not work in the fast moving and highly interconnected systems of our disruptive world. For example, the emergent behaviours of complex systems cannot be controlled or predicted in the sense that typical causal logic or reductionist analysis would suggest, or that current practices rely on.

Conclusion: regulation fit-for-complexity

Rapidly changing scientific, technological, and societal developments, coupled with ever-increasing interconnections across social, physical, and natural infrastructures, are a feature of today's world. They are bringing many opportunities for beneficial innovation.

However, the deployment of these innovations in areas such as AI, autonomous systems, and healthcare is also creating inherently complex systems with seamless interconnectivity and multidimensional risks. The results are close-coupled systems with integral systemic risks that have the potential for immense direct and indirect costs should they crystallise. This new reality presents a profound challenge for regulators, and a powerful catalyst for regulatory innovation.

As a starting point, it will be essential to distinguish between many conventional regulatory issues, where existing practices will continue to work well, and the much fewer complex ones requiring a radically different approach.

A new mindset

History has shown how regulatory and legislative tools can be successfully developed in response to new demands. We may well find that the challenge we face lies not in the new methods, but in recognising when the old ones are no longer relevant.

But this is not where the biggest transformation will be required. What is most needed to achieve regulation fit-for-complexity, more than any new tools, is a new mindset fit for this disruptive age.

That new mindset means:

- Acceptance that we navigate rather than control complex systems as the illusion of control is particularly dangerous. That runs counter to political, societal, and business desire for certainty.
- Acceptance that the question is when, how often, and to what extent regulatory designs, laws, and rules will need to be adapted. Institutional inertia is a significant constraint.
- Acceptance that we cannot tackle complexity in silos. This places an even bigger premium on inclusiveness, perceived fairness, and trust as essential lubricants of regulation.

This new mindset requires widespread acknowledgement of the issues being faced: a complex, TUNA (turbulent, uncertain, novel, and ambiguous) environment [53] where policymaking and regulation take place under conditions of uncertainty across society as a whole, and where the potential scale of any future failure will be at a different pace and of a different magnitude to those previously encountered. We need regulators, business, and the public to collectively understand the risks that coexist with the benefits of disruptive change and complexity if we are to achieve real progress. Without this, the risks are further magnified.

Implications for regulatory design

We adopted the term 'regulatory system' to capture not only the 'hard powers' (such as, formal rules, enforcement) available to a regulator, but also the 'soft powers' (such as, influence, coalitions, data sharing) that enable desired behaviours to be shaped. It also reflects the multiple entities and variety of interactions involved.

As regulatory systems are highly contextual, there will not be a 'one size fits all' answer to regulating for complexity. High quality designs will require the assembly of different but complementary approaches, using the full range of tools available (see Annex A) and with those options likely to change over time.

Existing regulatory tools and concepts will undoubtedly evolve to respond to these demands, augmented by regulatory adoption of innovative technologies such as AI and sensor networks. However, the laws and formal rules underpinning regulation are unlikely to be able to fully address complexity. This is because of a fundamental tension between their characteristics (general, impartial, predictable, framed by precedent) and the emergent behaviours, multiple actors, and dynamic multidimensional interactions inherent within complex systems. We may therefore see 'hard powers' used in more specific, targeted ways, giving increased emphasis to 'soft powers'.

Timing is crucial: there is typically a window of opportunity before (for example) digital systems have an established presence and locked themselves in by becoming the de-facto standard.

Design attributes that could (in combination) support the new mindsets are as follows.

Navigating complexity requires a map and a compass.

The map sets out not only what we know about the SOI but is equally clear on what we do not know. The intent is to acknowledge and then remember where the hard limits of our knowledge, capability or regulatory methods lie, and hence where to apply due caution as we approach these. It could also show where 'firebreaks' can be inserted (potentially through regulation) to retain control over discrete elements of the system.

Given the uncertainties, ambiguities, and dynamics of complex systems, we might expect to see risks such as: mismatched pace or knowledge between technological innovation and institutional ability to respond; misaligned boundaries between the system to be regulated, and regulatory mandates; the potential for amplification or rapid cascade of local failures.

The compass comes from clear leadership and shared clarity about the problem being addressed, what the intended outcome is (in general terms), and a sense of direction.

Instilling a sense of chronic unease as we navigate this system then helps us remain alert to the realities of fast-moving, highly interconnected systems, where solving one problem can surface other unexpected issues.

Adaptive regulation requires an ability to anticipate, monitor, adapt, and regulate. Monitoring the multidimensional challenges, pace, and uncertainties of disruptive worlds needs multiple levels of insight, and multiple approaches. Sensor networks, whether human or using innovative technologies, have been proposed to anticipate, spot, and react to emerging risks.

These will have to be augmented by alerts and fast review, learning, and redesign capabilities that ensure timely adaptive responses to the faintest indication of abnormal behaviours.

However, the regulatory and institutional inertia inherent in traditional structures is not conducive to the anticipatory designs we need. The concepts of polycentric governance offer a possible option, by integrating the oversight and direction setting of a centralised regulatory authority with the expertise, practical know-how, and pace of independent local decision-makers across a specific domain. This does not rely on anticipating a specific type of disruption, but instead invests in the dynamic mechanisms and network capabilities that can invoked as needed to fill knowledge gaps as new threats emerge.

The emergent behaviours of complex systems create a specific challenge. If these behaviours render causality indeterminable, with multiple actors involved, how do you establish accountability (a 'dutyholder')? How do you enforce 'polluter pays' if you cannot show with confidence who created the harm? How do you encourage ownership of the risks? It is worth exploring further whether the concept of 'joint and several liability' (widely applied in commercial law) could be applied in regulatory contexts. This would still rely on being able to characterise the entities within a system and for the expectation of liability to be meaningful, if intended as a deterrence to poor behaviours.

Finally, blending of old and new approaches brings its own challenges: existing laws, rules, and potentially regulators may need to be redesigned or culled alongside introducing new ones.

Inclusivity and trust require extra sociotechnical measures to be incorporated into regulatory designs. Addressing complexity will be need inputs from a diverse range of sources. It is likely to bring together individuals from very different types of organisations and a wide mix of disciplines (spanning formal, natural, and social sciences). This breadth of perspectives can be further enhanced (and trust built) by engaging interested individuals from outside established institutions, who may not have what is seen as the 'usual' professional or academic background.

This will require substantial investment in relationship building, in 'decision science' capabilities, and in overcoming the different disciplinary languages that can get in the way of collaborative work. With many of the frequently used methods relying on expert judgement, safeguards are also needed to mitigate pitfalls such as cognitive bias (which may manifest in, for example, being dismissive of nontraditional experts or being unwilling to listen to those challenging the status quo) and ensuring that cognitive diversity is retained over time as homogenisation of knowledge increases. This homogenisation could be compounded by generative AI tools learning largely from each other, with limited diversity of source data or human intervention.

Sustaining public trust is crucial, particularly if the pace of change and uncertainties place a focus on coping and adaptation (as opposed to the more usual expectations of control and certainty). Recent research[52] sets out the drivers of trust and distrust on the governance of significant technological innovations. It highlights the importance of factors such as regulators being more open, visible, and showing positive impact; demonstrably focusing on the public interest (not ideologies); and getting good at ethics, values, and stakeholder and citizen involvement.

Issues arise when the regulatory system is visibly not working well or is at odds with what the public views as 'fair'. When the playing field is not level, when the burden falls disproportionately on those who are least able to bear it or enforcement fails to address free-riding, it will be very hard to ensure cooperation or regain societal trust.

Preparing for complexity

We can and should be preparing for disruption while the intellectual and temporal resources to do so remain available. Approaches set out above will be difficult to put into practice. It will need clarity, resources, and capabilities that may not currently exist, and leadership to instil cultures of chronic unease, constant adaptation, and open communication.

There also remain big questions to resolve, for example: under what conditions will an increasingly fragmented society accept uncertainty and adaptation? How do you ensure fair regulatory systems, when these may depend on who is at the table creating them and whose voices are heard? How do you secure accountability and liability if causality is indeterminable?

Global debates around regulation of risks linked to, for example, AI, autonomous systems, climate change, creates impetus for regulatory innovation. The opportunities are there to test and develop these ideas further. It will need leadership, collective awareness of the issues, and new mindsets if we are to make meaningful progress towards regulation fit-for-complexity.

Annex A: a regulatory toolkit

We use the term regulation to reflect the act of regulating a business activity, capability, or sector to achieve desired business and individual behaviours. A regulatory system describes the totality of those organisations involved (supporting or on the receiving end of regulatory activity), their interactions and the regulatory tools applied to achieve a given regulatory outcome.

Governments have a wide variety of tools and need to think about the whole spectrum of options available to them.[54] These range from providing advice, gathering information not available to others, and influencing with economic incentives through to introducing and enforcing legally binding rules (which can go from light touch to heavy handed).

In looking beyond the use of formal laws or rules, thinking in terms of a 'regulatory system' recognises the breadth of tools available to regulators in shaping regulatory outcomes.

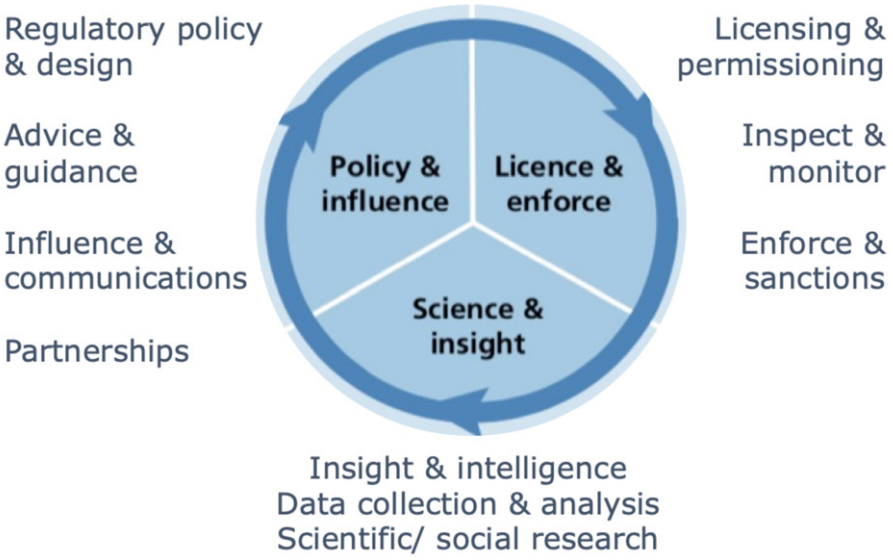
Figure A.1 illustrates frequently used regulatory tools grouped within three interrelated categories, together with some of the enablers that support their application.

Ultimately, the art of regulation lies in making skilful use of available tools, often in combination. These tools may be supported by specific methods or processes: for example, granting a licence may rely on the operator demonstrating their ability to manage risks through use of a safety case.

Market driven initiatives can also be used alongside (or integrated within) regulatory frameworks. These still need good design: fear of civil litigations, insurance needs, and supply chain demands can have a greater cumulative impact on small businesses than legislation itself.[55]

Further detail is provided in our previously published Foresight Review.[1]

Figure A.1 – tools of regulation [1]



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Workshop 1: Regulation fit-for-complexity – London (in person) 22 June 2023

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Workshop 2: Implications of complexity for laws and regulations – (virtual) 16 August 2023

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