Preventing breakdowns in the adaptive governance of fire-retardant chemicals

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Abstract

Adaptive governance, originally coined to refer to governing socio-ecological systems in the face of complexity and uncertainty, can inform the ability of policies to evolve and learn in the face of disruptive (discontinuous, transformative, breakthrough, groundbreaking, game-changing) technological developments (innovation). Ideally, adaptive governance strikes a balance between allowing for technological innovation while mitigating the risks associated with run-away development. Yet, attempts at adaptive governance may break down and get stuck while achieving neither.

This contribution examines the advent of fire retardants in the 1970s as a disruptive technology, one that allowed for a fundamentally new way of dealing with the age-old problem of fire risks by chemically treating surfaces and materials. The 1976 Toxic Substance Control Act (TSCA) offered a form of adaptive governance that sought to govern their entry into the market while assessing risks in a manner that ensured the new technology would evolve towards better and safer alternatives. Yet, TSCA proved unable to adapt, not in the face of the routine application of fire retardants to a rapidly widening range of products, not when confronted with the complex assessment of evolving custom-designed fire-retardant chemicals, and not in instances where socio-technical changes rendered fire retardants obsolete. Neither the ubiquitous detection of fire-retardant chemicals in endocrine systems nor their proven health risks led to increased scrutiny. The result was a techno-institutional lock-in between federal and state regulators, affected industries, and consumer-protection advocates.

Since 2016, the Lautenberg Amendment to TSCA offers a retooled adaptive governance format, which more explicitly aims to address the increasing complexity and uncertainty surrounding these chemicals through continuous learning and innovation. The question remains whether the new regulatory regime supports the type of learning that is needed to innovate beyond the ever more sophisticated use of chemicals to suppress flammability, whether it allows for disruptive innovations in other words, which have the potential to propel a technology and/or its sociological environment into a whole new direction.

This contribution examines these two junctures - the introduction of fire retardants in the 1970s and their recent curtailment - by identifying breakdowns to their adaptive governance with the goal of identifying opportunities to improve the adaptiveness of associated risk assessment processes. Studying potential breakdowns in adaptive governance is significant because they stand in the way of fostering governance regimes within which innovation can thrive while keeping tabs on harmful developments and undue risks.

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Introduction

Flame retardants are chemical additives in industrial and commercial products to prevent or slow their flammability. While efforts to develop flame-retardant materials date back hundreds of years, fire-proofing needs proliferated with urbanization and industrialization in response to increased fire risk. The way Tetra phosphonium chloride (THPC) could be added to different materials, starting in the 1950s, propelled regulatory developments toward mandatory flammability tests. Rapidly evolving chemical innovation led to the application and addition of flame retardants to a wide range of materials and products, which inspired ever tighter product safety and flammability standards while propelling research to develop effective and low-cost flame-retardant chemicals.

Polychlorinated biphenyls (PCBs) flame retardants were soon found to be toxic and banned from use in the 1970s. Industries started using brominated flame retardants instead, remnants of which were then found in the environment and organisms. By the 1990s, the environmental and health behavior of flame retardants received sustained attention, which triggered efforts to curtail and regulate their use. The European Union banned several types of polybrominated diphenyl ethers (PBDEs) in 2004 and 2008, and US states began to regulate the use of flame retardants in children's products, furniture, and clothing. Such regulatory action proved difficult and erratic due to the chemical specificity of flame retardants, which can be custom manufactured to fit select materials and uses. In conjunction with difficulties of regulators to keep up, these innovations led to a regulatory "whack-a-mole", whereby new fire retardants are developed, regulated or banned, then retooled and brought back to market in a modified manner or for a different use. Meanwhile, these persistent, bioaccumulative, and toxic (PBT) chemicals continue to permeate the environment, where they may be chemically transformed following fires, when diluted in rivers, entering food chains, or leaking from waste sites. The governance of fire-retardant chemicals thereby touches on many adjacent (and themselves evolving!) problem fields. In a complex and rapidly evolving socio-technical system, chemical innovations interface with product innovations and they, in turn, meet evolving product needs and consumer behavior.

Considering the inherent challenges that the rapidly evolving socio-technical developments pose for the durability of policy solutions, flexible policies are needed to their reduce health and environmental risks while facilitating continued innovation towards finding better chemicals as well as non-chemical flammability solutions. The need for “complex, adaptive, multi-layered institutions capable of harnessing technology’s benefits [by continuously innovating] while also addressing its risks, equitably, and expeditiously” (Baehler 2022: 1) is evident, if incredibly challenging to realize. Likewise, the inherent fragility and instability of associated governance arrangements is widely acknowledged (((xxx))). Solutions – in the form of recommended arrangements, or at least principles to govern such arrangements – are in comparatively shorter supply: they should be decentralized, heterogeneous, networked with nodes taking on varying functions (Baehler 2022: 26), and bestowed with “intelligent coordination” and “large repertoires of responses [to react] adaptively to challenges” (Baehler 2022: 26).

Assuming such adaptive governance arrangements can be built and sustained and knowing they are notoriously fragile and unstable, especially when technological “disruptions” occur, the question becomes what can cause them to break down, and how to prevent, spot, and redress such breakdowns**.** In this contribution, the governance of flame retardants will serve as a case study of the challenges to adaptive governance frameworks in the face of “disruptive technologies”, defined as (discontinuous, “game-changing”) socio-technical developments.

In the next section, this paper offers a brief history of flame retardant policy in the United States. It then defines “disruptive” technologies’ distinctive features and associated market and government failures and applies these to the emergence and rapid diffusion of flame-retardant chemicals in the 1950s and 1960s. The third section examines the regulation of flame retardants through the lens of adaptive governance as a solution to the aforementioned problems, first by defining the key tenets of adaptive governance from the vantage point of governing disruptive technologies, then by tracing the (quasi-)adaptive governance of fire retardants through the 1986 Toxic Control and Substances Act (TSCA). The fourth section then turns to examining breakdowns in the (quasi-)adaptive governance of fire-retardant chemicals by showcasing how and why TSCA fell short of its aim of flexibly (and adaptively) balancing risks and continued innovation in a rapidly evolving socio-technical context. The paper concludes with tentative lessons learned and applied to the 2016 reforms administered to TSCA in an effort to render it more adaptive to future developments.

Background: A Brief History of Flame Retardant Policy in the US

Keeping inhabitants safe from fires and eliminating fire hazards is amongst the oldest challenges governments face, especially in densely populated urban areas. The Great Chicago Fire of 1871, which killed 250 people, left 100,000 homeless, and destroyed 17,400 structures across 2,000 acres, was a dramatic reminder of the need to combat fires from ignition to extinction. To this day, fire retardation is one piece of that puzzle. Fire retardation refers to strategies designed to slow materials from catching or sustaining fire.

With the advent of chemical innovations in the 1950s and propelled by the expansion of cities and modern consumer culture, the use of chemical flame retardants, which are applied or added to otherwise flammable materials to slow or prevent the start and growth of fires, became the predominant mechanism to prevent and slow fires. Flame retardants saw a massive explosion in use as the United States entered the second half of the twentieth century. Polybrominated diphenyl ethers (PBDEs), a class of brominated flame retardant (BFR), were among the most widely used and proliferated flame retardants throughout the 20th century. PBDEs along with other classes of flame retardants were commercialized during the post-World War II manufacturing boom of the 1950s and 1960s in response to the increased need for flame resistant products in manufacturing, construction, transportation, and retail goods (Stapleton et al., 2011). By the 1970s, flame retardants were routinely applied to clothing, furnishings, upholstery, electronics, and a wide range of construction materials.

With their ubiquity came a system of near-constant environmental exposure and the persistent nature of PBDEs led to buildup in humans, animals, and waterways (Brown & Cordner, 2011). In 1973, the state of Michigan experienced the pervasive effects of PBDEs because of the Michigan Chemical Livestock Feed controversy when bags of PBDEs were inadvertently mixed with animal feed, resulting in the widespread contamination of farm animals and residents who consumed contaminated meat and milk or worked on contaminated farms (Egginton, 2009). While this contamination made national headlines, it did not result in increased scrutiny or regulation of chemical flame retardants. Rather, propelled by product standards and building codes, their use kept expanding and accelerating, in part due to the expansion of flammability standards that increasingly required their application or made their use indispensable to pass mandated flammability and safety tests.

In 1975, in response to the steady uptick of house fires beginning with the 1950s manufacturing boom, the California Bureau of Home Furnishings and Thermal Insulation mandated a “smolder test”, with which it required furniture foam to withstand an open flame for twelve seconds without igniting (Coyle, 1992). This smolder rule further accelerated the use of flame-retardant chemicals. Because California’s furniture market was so large, manufacturers found it impractical to develop furniture for the greater United States that did not also comply with California state law (Stapleton et al., 2009). Recognizing the value of flame retardants for the protection of life and property state and federal regulators supported the proliferation of PBDEs and other classes of flame retardants, even amidst rising concerns over their toxicity and ensuing health risks.

In response to emerging concerns over the proliferation and persistence of potentially harmful chemicals during the 1970s, the 94th United States Congress passed the 1976 Toxic Substances Control Act (TSCA). TSCA sought to establish oversight on emerging chemicals before they entered the market to prevent known toxins from proliferating throughout the environment. TSCA did not codify chemicals as “toxic” or “non-toxic” but prohibited the manufacture and distribution of chemicals that were registered within the EPA’s TSCA inventory. With this initial reporting requirement, TSCA fulfilled a key tenet of adaptive governance by attempting to establish a framework for continuous learning within a single policy that allowed for adaptation without the need to pass additional laws. Because every chemical manufactured and sold within the US would ideally cross the desks of TSCA regulators, the EPA could provide oversight on chemical markets without needing to rely on Congress to pass judgment on individual chemicals. However, TSCA did not require existing chemicals to undergo a new round of evaluations, and the EPA was required to pass Significant New Use Rules (SNURs) to regulate chemicals that were found harmful in retrospect, after the 1979 implementation deadline for TSCA.

Because TSCA did not automatically require existing chemicals to be re-evaluated, absent a deliberate commitment of EPA resources to their evaluation, many compounds on which the industry relied heavily remained shielded from EPA’s oversight. As one of the most ubiquitously used preexisting classes of chemicals in global industry and manufacturing, TSCA did not affect their use. Even PBDEs, which made dramatic national headlines in 1973 due to the above-mentioned contamination in Michigan and ensuing health effects, were not targeted by significant regulation at the state or national level.

Following advances in biomonitoring research during the 1980s and 1990s, studies were able to demonstrate long-term trends in chemical buildup, and subsequent consequences experienced by humans and animals (Cordner, 2016). Research showing the accumulation of PBDEs in certain biomarkers and demonstrating their potential to act as endocrine disruptors raised alarm (Hooper & McDonald, 2000). In 2000, the EPA established a PBDE Action Plan in response to spreading concerns about the chemicals' impact on human and environmental health (Cordner, 2016). The public's awareness of the toxicity of everyday products brought about by fire-retardant chemicals further grew post-9/11 due to the health effects that first-responders suffered who helped sift through the Twin Towers rubble to recover remains.

The first regulatory efforts aimed at PBDEs occurred in 2003 in California, where A.B. 302 effectively banned the sale of products containing Penta- and octaBDEs by 2008. Other state-level and federal efforts followed in short order. By 2006, eleven other states enacted some form of anti-PBDE regulation. By the end of that year, the EPA issued SNURs for both penta- and octaBDE (Corder, 2016). In 2008, the National Institute of Standards and Technology (NIST) started evaluating the toxicity of nanomaterial-based fire retardants. In 2009, a SNUR was implemented for decaBDE, which had by then become the most prevalent PBDE. In December 2009, three Deca manufacturers announced a voluntary agreement with the U.S. Environmental Protection Agency to end production of decaBDE for most uses by the end of 2013. The chemical industry turned to newer "replacement" chemicals to fulfill fire retardancy needs and requirements.

In 2016, the 114th Congress passed the Frank R. Lautenberg Chemical Safety for the 21st Century Act. With the passing of the 2016 Lautenberg Amendment to TSCA, the EPA now has a mandatory duty to evaluate existing chemicals based on clear and enforceable timelines, thereby filling a significant gap in the TSCA, one that had thus far allowed many pre-existing fire-retardant chemicals to escape scrutiny. The Lautenberg Amendment also expanded the EPA's authority to request chemical information to test existing chemicals. Moreover, TSCA's focus on balancing risks against benefits and costs against benefits was replaced with a higher regard for risk-based safety standards and the elimination of unreasonable risks. In effect, the

Lautenberg Amendment not only introduced a new mandate to evaluate existing chemicals but also significantly expanded the requirements for new chemicals entering the market. Under the Lautenberg Amendment, the EPA listed several replacement PBDEs as requiring further research. Fire retardants also received added federal scrutiny through the Consumer Product Safety Commission (CPSC)'s rulemaking powers under the Federal Hazardous Substances Act (FHSA) and the Consumer Product Safety Act (CPSA). In 2017, the CPSC stepped into action "to assess and issue a report on the risks to consumers' health and safety from the use of additive, non-polymeric organohalogen flame retardants (OFRs)"[1].

Failures Associated with "Disruptive" Technology & Innovation

During their initial development and rapid expansion in use, flame retardants exhibited key attributes of "disruptive technologies" or "disruptive innovation", a term whose popularization is attributed to Bower and Christensen's "Disruptive Technologies: Catching the Wave" *Harvard Business Review* article (Bower & Christensen, 1995). Not only that, the more recent proliferation of custom-designed fire-retardant chemicals is reminiscent of Moore's Law[2], which (based on research in the semiconductor industry) posits an exponential – i.e. roughly doubling – speed of innovation as production progresses. Moore's Law is no longer a widely accepted truth – even in the realm of semiconductors –, rapid advancements in other forms of computing power, from cloud-based technologies to artificial intelligence (AI), have allowed exponential growth to continue (Theis & Wong, 2017). What distinguishes "disruptive technologies" is their "exponential expansion" and their "potential of severely disrupting the entire political, economic and social […] order" (see Majumdar et al., 2018).

While that strand of research was developed for an entirely different purpose – namely to highlight the "innovator's dilemma" (Gilson, 2010: 908) of notoriously missing and therefore underinvesting in novel (and potentially "disruptive") technology – the concept can be harnessed

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[1] U.S. Consumer Protection Bureau. "Flame Retardants". Retrieved on October 20, 2023: https://www.cpsc.gov/Business--Manufacturing/Business-Education/Business-Guidance/flame-retardants
[2] In 1965, Gordon Moore captured this idea of exponential growth in innovation and tailored it to the semiconductor industry, where prior to 2017, he estimated the average number of transistors contained within dense integrated circuits was doubling biannually.

here to characterize the failures that occurred that led to the excessive development and ongoing challenges posed by flame-retardant chemicals as well as the continued disregard for developing wholesale alternatives to combatting flammability via chemical means. What makes technologies “disruptive” [3] is that they fundamentally transform not only established technologies and associated business models and markets, but also prevailing governing rules and social systems (see Kaal & Vermeulen, 2017).

Just as “disruptive innovation” and the “innovator’s dilemma” would predict, the initial development of flame retardants was a relatively slow niche occurrence, one that the government discovered and spurred when faced with flammability challenges in the aerospace sector[4]. It was only when that innovation met the demands of a large array of consumer products and building needs that the application of flame-retardant chemicals spread exponentially and ultimately became ubiquitous.

That ubiquity quickly surpassed an “optimal” level of use, fueled by several common market failures:

- The highly concentrated chemical industry, when eventually sold on these new chemicals, quickly built dedicated production sites, and settled into the sufficiency of readily and cheaply available flame-retardant chemicals, thereby stifling the proactive innovation of more nimble and less toxic solutions.
- Within the supply and production chain of end-user products, externalities and information asymmetries led to an overapplication of fire-retardant chemicals. For example, while raw materials such as fabrics and foams for furniture may encounter varying uses and therefore varying needs to meet standards regarding flammability and combustion, producers of such materials have little interest in differentiating their production accordingly and the users of these materials (e.g. furniture manufacturer) lack the knowledge or awareness to adjust relevant product specifications.
- Flame retardants are not visible to consumers. Even when labeling may require their disclosure, consumer awareness of complex chemical compounds and their potential health risks typically lag far behind the often already lagging discoveries and publicization of long-term impacts.

[3] See Xu et al. article related concepts used in the vicinity of "disruptive".
[4] (((Add details about the astronauts killed from ignition and combustion in their cockpit during a simulation.)))

- Even when faced with raising consumer awareness, as is the case with Ikea's quest to remove flame retardants from mattrasses in response to consumer concerns, markets are slow to react to such demands, not only due to the concentration of relevant industries and the stickiness of their production systems, but also because many product components are stocked, which is drawn on over long periods of time. What's more, in a globalized market, product components tend to meet and sometimes exceed the most demanding of product standards to pass muster in varying markets and across many countries.

As a "disruptive technology", the emergence of flame retardants not only durably challenged primary and secondary markets – from chemical industries, to developers of raw materials, to product retailers, to builders, to consumers – but also altered associated social and regulatory systems. California's 1975 "smolder rule", which in effect became a national (if not international) standard, whereby an expanding array of products needed to meet tightly defined flammability standards irrespective of their use, would be unthinkable without this technical innovation. The smolder rule not only set new regulatory standards but ultimately reshaped how regulators, chemical experts, industry stakeholders, and the public thought about flammability, namely as a technically preventable occurrence related to flammability and combustibility.

The government's failure to steer this socio-technical system towards a more "optimal" and sustainable use of flame retardants, and to do so more rapidly, is attributable to several inherent dynamics. When faced with a disruptive technology problem, governments must maintain a delicate balance between promoting benefits granted by an emerging technology and mitigating poorly understood potential harms.

1. **Rapid (Exponential) Diffusion Through Consumer Markets**
   The core definition of "disruptive" technologies is their rapid (exponential) spread, whereby business models, markets, and their support networks are fundamentally altered. Ubiquity is achieved within a dynamic socio-technical system at a rate that not only prevents any reversal but also the development of a "before-and-after" framework to examine impacts. For example, the intertwinement of big data and politics in the 2010s achieved utilization in ways so far-reaching, any attempt to understand how a political event in the 2010s would have unfolded without it is impossible.
   Once brought to market, flame retardants quickly became a solution to many protracted

flammability problems. Propelled by highly visible concerns over the flammability of new materials, their prevalence in consumer products, such as clothing, toys, and emerging electronics (e.g. TVs), quickly became the norm. Flame-retardant technology diffused rapidly through consumer markets. They quickly achieved household ubiquity as an additive not only to mattresses and other furnishings, but also to carpeting and building materials.

2. **Technological Development is Driven by Perceived Benefits**
   A disruptive technology's spread is driven by perceived benefits, while potential harms remain unthinkable or poorly understood. This is because emerging technologies may occupy a realm of science where relevant impacts are not considered, not yet recognized, or not yet fully understood. This principle applies to innovations whose impacts we no longer question: For example, the printing press significantly increased the societal availability of knowledge and was instrumental in driving social progress and technological innovation for centuries. Yet, the printing press also encouraged the mass production of misinformation, libel, and propaganda.
   As a ready and effective tool to protect consumers and their livelihoods from fire damage, their perceived benefits redefined the age-old problem of flammability as one that chemical additives could solve. Policies requiring their application in certain industries and brushing aside timid attempts to prevent their use, not only accelerated their diffusion but also enabled the development of complex supply chains dependent on flame retardants throughout various consumer markets (Cordner et al., 2016), *thus quickly altering not only the above-mentioned supply network but also the perception of the problem itself: The problem of flammability was displaced by that of finding ever more effective and safer fire-retardant chemicals*.

3. **Lack of Evidence for the Limits of Applications & Associated Harms**
   Focused entirely on benefits to solve a (reframed) public problem, the scientific nature of the new technology is incomplete and initially impossible to examine without real-world applications. For example, the limits of AI applications have yet to be qualified and quantified while associated technologies are rapidly transforming areas ranging from academia to national defense. Attempts at studying the impacts of AI with existing evidence is impossible.
   Alongside their exponential and predominantly benefits-focused diffusion, it became

quickly apparent that the limited lifespan of certain flame-retardant chemicals and associated chemical degradation caused their widespread environmental proliferation (Kefani et al., 2011)*. Many families of flame retardants, particularly brominated flame retardants, proved highly persistent within living organisms and the environment, as the varying levels found of since banned chemicals to this day throughout key human biomarkers - from bone marrow to breast milk - demonstrates* (Pazin et. al., 2015)*. Brominated flame retardants (BFRs) are so bioaccumulative, testing has shown 97% of US residents may have traces within their blood* (Samani & van der Meer 2020)*. BFRs act as endocrine disruptors* (Kim et. al., 2014) *and contribute to mitochondrial disorders (Pazin et. al., 2015).*

4. **Existing Governance Structures Cannot Adapt to the Problem**

   The fourth characteristic, driven by the first three, implies the problem has exceeded the governing limits of existing policies. Governments are unable to govern a problem that cannot be understood in time to be adequately regulated unless a governing structure is implemented with the capacity to evolve alongside the shape-shifting nature of a disruptive technology.

   Flame retardants, alongside other persistent, bioaccumulative, and toxic (PBT) chemicals, failed to receive the attention of policymakers for decades. Even after the implementation of TSCA in 1976, brominated flame retardants were not targeted by the EPA until the early 2000s. While several classes of brominated flame retardants have been phased out, their strong bioaccumulative properties and prior ubiquitous use has allowed for their presence in animals and the environment to remain high (Cordner at al., 2015)*. The existing governing structures of the twentieth century within the United States failed to properly identify and manage the challenges of flame retardants leading to long-term consequences and ongoing governance challenges. What's more, over the concern of undoing their harm while still finding safer chemical alternatives, attention to wholly new approaches to addressing flammability problems continues to remain elusive.*

Disruptive technologies, ranging from synthetic biology in food and agriculture (Bubela et al., 2012; Baehler, 2018), to the use of artificial intelligence (AI) for national security purposes (Haney 2020), to the proliferation of unmanned aerial vehicles (UAVs) (Li & Kim, 2022) have raised alarms over the ability of regulators to keep up with rapid and shape-shifting innovations. Disruptive technologies present a unique governance challenge, as high potential benefits are accompanied by a high degree of social, health, or environmental risk. Not only do disruptive technologies require responsible innovation to promote their benefits while quickly adapting to unforeseen externalities, but they also need to allow for equally disruptive innovation to escape those externalities. How disruptive technologies work and how they are perceived impact policies (Cath 2018) and thereby our ability to strike a balance between fostering innovation and managing risks.

Adaptive governance offers compelling solutions to this conundrum, but it is in turn prone to breakdowns, which will be the subject of the last part of this paper.

The Regulation of Flame Retardants Through the Lens of Adaptive Governance

Governing Disruptive Technologies Through Adaptive Governance

The urgent need for breakthrough developments to combat the COVID-19 pandemic[5] (see De Grandis et al., 2022), to address cyberthreats (Porter & Tan, 2023), and to harness artificial intelligence (AI) (((XXX))) are key areas that brought disruptive technologies to the attention of "adaptive governance". At the core of the nexus between disruptive technologies and adaptive governance is the aim to allow for or even promote – rapid, exponential – innovation while managing risks to consumers by making regulations "flexible and adaptive" (De Grandis et al., 2022), also referred to as "agile" (Porter & Tan, 2023).

Empirical adaptive governance research refers to its key tenets as "critical requirements" (((XXX))), "methods" (Sharma-Wallace et al., 2018: 178), or "solution categories" (Baehler & Biddle, 2018: Fig. 1). When cross-checking them with the above-mentioned distinctive characteristics of disruptive technologies through the works of Macnaghten et al. (2005), Greer & Trump (2019), and De Grandis et al. (2023), the following four tenets emerge:

[5] In late 2020, seven nations signed the Agile Nations Charter (2020) prioritizing areas of cooperation including artificial intelligence, transportation, and healthcare. The Charter released their first Work Programme (2021) in October the following year with the goal of developing "pro-innovation" regulatory practices for these and other focus areas. (see De Grandis et al., 2022: 2; World Economic Forum, 2020)

1. **The disruptive (exponential) pace of development inherently challenges existing governance mechanisms, incrementally and probably toward a life-cycle approach:** By nature, an emerging disruptive technology will stress governing structures and require the action of policymakers in ways that the existing structures likely did not foresee. Adaptive governance emerges in response to existing governance limitations, whether as an ad hoc response to a single problem or in the form of a broad-ranging policy shift. In other words, adaptive governance is by its very nature evolving, most likely incrementally and in the direction of formerly disregarded input or outcome considerations and hence toward a life-cycle approach, i.e. one that becomes inclusive of formally disregarded input and outcome information from production to disposal.

2. **Adaptive governance limits information asymmetry through upstream engagement:** Disruptive technologies are fraught with information asymmetry that prevent policymakers and stakeholders – including industry, consumer advocates, and the scientific community – from understanding the nature of the problem and the scope of solutions. Adaptive governance prioritizes upstream stakeholder engagement to mitigate information asymmetry and prevent ensuing externalities, in an implicit or explicit effort to facilitate development while protecting the public from harm.

3. **Adaptive governance prioritizes learning through continuous data collection:** The shapeshifting nature of a disruptive technology requires continuous (feedback-focused) learning to be built into the structure of adaptive governance. The nurturing of independent data collection streams fosters a diverse data pool. Upstream stakeholder engagement supports this aim (see #2). Adaptive governance offers built-in pathways for data collection and analysis in response to new bodies of evidence, thereby allowing for an adaptive ease or tightening of restrictions without the need for new rules and policies (Greer & Trump, 2019). This form of engagement takes an "upstream approach", whereby regulators are actively involved during the early stages of a product's development cycle, supporting continuous learning, and allowing industry to take advantage of "facilitating regulatory pathways" (DeGrandis et al., 2022) while safeguarding risks to consumers.

4. **Policy change is built into the policy itself:** Critical to the execution of adaptive governance is the assumption that an adaptive policy can rapidly meet new challenges

without the need to implement new policy. Adaptive governance must quickly and effectively respond to the shapeshifting nature of a disruptive technology problem through its own adaptive elements, including discretion granted to governing bodies that allows them to adapt existing regulatory frameworks to strike a balance between protecting consumers and facilitating innovation.

(Quasi-)Adaptive Governance of Fire Retardants Through TSCA

The literature on adaptive governance in the face of disruptive developments in science and technology tends to focus on new and emerging technologies, which fire-retardant chemicals no longer are. However, the retrospective examination of the 1976 TSCA's decades-long implementation can shed light on the "adaptive-ness" of existing (quasi-adaptive) policies and point to sources of "breakdowns" in governance of fire retardants, a once disruptive, new and fast-moving disruptive technology. Not only that, TSCA's 2016 revision in the form of the Lautenberg Amendment may reveal how "adaptive" (quasi-)adaptive governance arrangements prove to be.

The adoption of TSCA in 1976 resulted from an effort to target rising cancer rates linked to the unfettered use of some chemicals (Markell, 2010). Prior to TSCA, the use of potentially dangerous chemicals was regulated under other environmental statutes, which disregarded risks from bioaccumulation. By creating TSCA in 1976, Congress responded to a problem growing both in scientific understanding and public perception. While the problem of PBT chemicals had solidified itself long before Congress acted, TSCA filled a critical policy gap by bringing much needed oversight to the chemicals industry. With TSCA's adoption, U.S. chemical policy developed the beginnings of a framework for adaptive governance of chemicals and their potential risks, in alignment with some tenets of adaptive governance:

1. TSCA required a **tiered risk assessment based on a "least burdensome" and life-cycle focused model** to evaluate the health, environmental, and social risks of select chemicals before EPA could approve them for manufacturing and distribution (Nabholz et al., 1993). Critical to a pre-approval risk assessment was the use of "structural activity relationships" (SARs), whereby a prediction is made between chemical structure and biological activity (Nabholz et al., 1993). Based on early advances in environmental risk assessments during the 1960s and 1970s, researchers could detect trends in chemical toxicity and

bioaccumulation. EPA was granted the ability to regulate new chemicals should a risk assessment provide an indication of “unreasonable risk” towards humans or the environment (94th Congress, 1976). Compounds initially classified as “low risk” were dropped from further evaluation, while the rest underwent a second evaluation process in which a more in-depth risk assessment was completed. While TSCA placed the onus of the evaluation process and final approval on the EPA, it fell on the producers to submit information, conduct tests, and complete the initial evaluation. While adding procedural rigor and tightening oversight, TSCA mandated the EPA protect the economy and innovation through the implementation of “least burdensome” regulations. The framers of TSCA thereby incrementally expanded the government’s oversight to mitigate risks while safeguarding the role chemicals played for current manufacturing and future discoveries.
An important limitation to TSCA’s incremental expansion towards considering a broader range of inputs and outcomes is the fact that it “did not extend to […] chemicals that were already regulated by other laws” (Schmidt, 2016: 183).
Because of the pre-existing ubiquitous and market-influencing nature of PBT chemicals, TSCA failed to fully address the problem. Flame retardants, through their previously described disruptive characteristics, were not subject to EPA regulation until the 2000s, and will be used as a case study in TSCA’s adaptive policy breakdowns.

2. A limited **upstream engagement process** was implemented through which the industry was required to provide the EPA with data on a new compound prior to receiving approval for manufacturing and distribution. This data was presented in the form of a Premarket Manufacturing Notice (PMN) and included chemical identity, molecular structure, projected production and use volumes, by-products, disposal methods, and estimated levels of human-exposure. Following receipt of a PNM, the EPA conducted an in-house chemistry review to determine the accuracy of the provided information, followed by an initial hazard assessment to determine the harm-potential of a new compound. TSCA’s establishment of an up-stream engagement process brought the chemical industry and the EPA together during the pre-approval process. Industry was required to have an information set prepared within a PNM during initial engagement with the EPA. While this form of upstream engagement was far from comprehensive, the entrance of new chemicals into the market began with collaborative interactions between the EPA and industry under the advisement of an independent chemicals advisory board.
   TSCA’s adaptiveness was curtailed not only by the lopsided (continually asymmetric)

availability of chemical information, which remained concentrated in the hands of the industry, but also by the limited reach of the independent chemicals advisory board. This is a key limitation the 2016 Lautenberg Amendment sought to redress by putting in place the more representative and publicly scrutinized Science Advisory Committee on Chemicals (SACC).

3. By requiring industry to submit PNM's, TSCA established a **system of continuous data collection with the goal of limiting the risk of externalities**. The PNM system used a two-stage bottleneck design to allow for broad data collection in the first stage, with more intensive and specific data collection for chemicals of concern during the second (Koch & Ashford, 2006). All new chemicals entering the market were meant to undergo a chemistry review and risk assessment under the EPA, requiring the agency to maintain a large chemical database, the Chemical Substances Inventory, and ensuring evaluators were well-practiced in the evaluation process. The second bottleneck designed for chemicals failing to receive a "low risk" designation implemented intensive risk assessments that had a dual effect of providing specific sets of data while testing the limits of the evaluation process. TSCA mandated the testing of existing chemicals and permitted the EPA to conduct discretionary testing at the recommendation of the agency's independent chemicals advisory board, the Interagency Testing Committee (ITC).
   The "adaptive" significance and reach of TSCA's governance design is significantly curtailed by the fact that EPA was allowed but 50 chemicals to be scrutinized per year and often chose not to pursue the full scope of its testing authority for existing chemicals (Koch & Ashford, 2006). (Neither the governance structure nor its implemented practice comes close to considering any disruptive technology's assumption of accelerating deployment.)
   Another significant limitation to the data collection tenet of TSCA's adaptiveness is the fact that there is, in effect, very limited public access to the chemicals inventory due to the industry's right to withhold "confidential business information" (Andrews & Wiles, 2009).

4. Aside from the presumed adaptiveness of the Chemicals Inventory, the 1976 TSCA offered **no built-in pathways for policy change**. The most flagrant violation of this tenet was the inability to compel new data for and scrutiny of existing chemicals, some of which may be discovered to cause previously unknown harm or experience previously unforeseen uses. "The only way the EPA could compel companies to generate new data on existing chemicals was by publishing a rule that would make it a requirement" (Schmidt, 2016: 183).

> Doing so hinged on the availability of data to press for such a rule, which could only be achieved based on the review of existing data, of which there was none, a veritable "catch-22" (Schmidt, 2016: 183).

TSCA's aggravating limitations to "adaptively" govern fire retardants were in part built into the Act's design, most notably by excluding existing (including fire-retardant) chemicals from its reach absent significant regulatory steps. The severe curtailment of the number of chemicals that could be evaluated at any given moment, recognizing their proliferation is in effect accelerating, is another "maladaptive" (Baehler, 2022) design flaw. So is the narrow confinement of upstream collaborative efforts away from socio-political input that could usefully detect not only novel scientific developments but also relevant shifts in underlying social patters, ranging from consumer practices to predominant fire hazards and firefighting practices.

It was not until severe pressure from consumers – via the court system and crippling regulatory developments at the local and state levels –, growing advocacy from national and international manufacturing intermediaries and retailers, and shifting epistemic communities (Walti & Bennett, 2019) that TSCA was revised in significant "adaptive" respects. The chemical industry and associated retailers found themselves ensnared in legal battles in an increasing number of states while simultaneously pressed to adapt by changing international regimes. In that context, the House Committee on Energy and Commerce, Subcommittee on Commerce, Trade, and Consumer Protection held a hearing on February 26, 2009, titled "Revisiting the Toxic Substances Control Act of 1976." Witnesses represented diverse perspectives, but all agreed that TSCA should be reviewed, and most supported at least some targeted amendments. Differences were apparent in views with respect to the value of the European Union's comparatively more adaptive REACH program and other laws as models for TSCA reform and the extent to which the basic elements of TSCA Title I should be changed. (Schierow, 2008). The result of that effort, in the form of the 2016 Lautenberg Amendment, sought to significantly expand TSCA's reach, in particular when it comes to bioaccumulative chemicals such as flame-retardant substances.

Yet, several paralyzing aspects grew out of what the next section of this paper refers to as "breakdowns" in the (quasi-)adaptive governance of fire-retardant chemicals under TSCA that could well resurface. An assessment of whether TSCA's enhanced adaptive design following the 2016 Lautenberg Amendment can forestall similar breakdowns informs that discussion.

Breakdowns in the Adaptive Governance of Fire-Retardant Chemicals

Adaptive governance is meant to balance consumer, environmental, and economic interests by promoting responsible innovation while containing risks. However, failures in execution may instead stifle markets and prevent technological breakthroughs; or they may allow excessive risk and harmful externalities. Under the following headings, we identify key “breakdowns” that have prevented flame-retardant policies from harnessing the above-mentioned opportunities of adaptive governance.

Breakdown 1: Failure to recognize increasing and shifting complexity through interdisciplinarity.

Governing a disruptive technology hinges on a rapid understanding of the resulting social, environmental, and economic impacts with the aim of recognizing and reacting to new realities of the entire socio-economic system. This not only entails a ready reaction to outcomes – whether they occur in the form of newly discovered (accumulated) harm or manifest themselves as excessive curtailment of emerging opportunities – but also sensitivity to new input.

TSCA’s PNM submission structure accounted for chemical toxicity and manufacturing use patterns. While comprehensive in terms of scientific data gathering, this approach did not account for social complexity nor for EPA’s limited regulatory capacity. As a disruptive technology, propelled by perceived benefits, flame retardants quickly spread through the market in multiple sectors. Cheap and readily available additives could be incorporated – sometimes for good measure – into many industrial and commercial products in a manner that significantly reduced fire hazards with little need to alter industrial processes and social behaviors.

Because flame retardant additives were inexpensive and readily available, the centralizing market forces toward adoption were met with little awareness and resistance. Amidst a dearth of toxicity data prior to 1990, unaware end users were slow to develop a level of scrutiny that could compel (furniture and other) retailers to push back such byproducts. By the time they did, the commercial sector had embraced (or been compelled to embrace) flame resistant products not only to prevent fires but also to hedge against lawsuits from fires. Besides, producers of carpeting, flooring, toys, and other goods had long developed supply chains that incorporated flame retardants along the entire chain of production. The result was a suboptimal fire-retardant "over-medication" of a wide range of products in households and the workplace, backed by a centralizing chemical industry producing them.

While, as a class of additives, flame retardants exhibit varying toxicity, brominated flame retardants were identified as a persistent bioaccumulative toxic substances (PBTs) by the late 1980s and early 1990s. Yet, regulatory intervention remained largely absent until the mid-2000s, even at the state and local levels, despite shifting social practices, such as the dramatically reduced prevalence of smoking in the home, the disappearance of curved screen TV that relied on fire-prone cathode ray tube technology, or the increasing penetration of home smoke detectors. With the advent of tobacco control policies throughout the latter half of the 20th century, smoking rates declined significantly from their levels during the 1950s and 1960s (Levy et al., 2004) while flame retardants were proliferating in use. Prior to the advent of anti-smoking policies and social trends, small ignition sources (including cigarettes) had contributed to many of the largest fires in history (Troitzsc 2013). Other fire prevention initiatives, from requiring fire alarms to improving indoor sprinkler systems, have significantly reduced indoor fire hazards.

The interdisciplinary incorporation of the social sciences could have detected if not predicted such trends, thus anticipating a socio-technological system's evolution beyond the narrow confines of chemical risk assessments (Macnaghten et al., 2005). The incorporation of the social sciences facilitates a responsible socio-technological development, one that is cognizant of the complexities and uncertainties inherent in consumer production systems, as described by Lowe et al. (2008).

Breakdown 2: Failure to compel coordination through ownership, control, and shared responsibility.

To address externalities resulting from the ubiquitous information asymmetries afflicting developments in science and technology and to combat the distinct market failures arising from disruptive technologies, adaptive governance tenets rely on (upstream) coordination. The burden of information generation, information provision, and continued innovation is thereby shared, or assumed to be shared. This requires ownership, control, and responsibility to be truly shared between stakeholders, from manufacturers, to distributors, to retailers, to consumers, to regulators.

TSCA was the first policy requiring the chemical industry to engage with a regulatory body in such a manner. TSCA theoretically gave the EPA powers to regulate chemicals, yet little was enforced in practice due to nearly insurmountable regulatory and procedural hurdles, even when it came to the assessment of new chemicals, for which TSCA was ostensibly designed. Although TSCA seemed to give EPA broad regulatory authority over the chemicals market, it narrowly curtailed EPA's attention to a limited number of chemicals and burdened the agency with the full scope of risk analysis responsibilities. While manufacturers were required to provide data in support of their PNM's, TSCA did not require preliminary toxicity testing, a time-consuming and expensive aspect of chemical evaluation. The EPA only received such data for around 50% of new chemicals (Auer et al., 1990). By neglecting to require industry to conduct the most important step in chemical risk evaluation, TSCA failed to address comprehensive industry ownership over new chemicals submitted for approval. Overly broad proprietary protections for the provision of information for public scrutiny and the regulator's burdensome focus on building a comprehensive inventory of thousands of chemicals in use.

Externality control should provide consumers with industry-disclosed technological information necessary for decision-making, while requiring industry to generate technological options for risk mitigation and to provide support for the development of databases such as the EPA's Chemicals and Products Database (CPDat) (Koch & Ashford, 2006). Instead, TSCA permitted the chemicals industry to operate without mechanisms to compel or at least incentivize cooperation and self-regulation. While the industry was generally acknowledged to possess greater access to their new substances' risk information (Koch & Ashford, 2006), by requiring the EPA to devote its limited resources to the inventory and chemical risk assessment process, the agency remained hamstrung – in a "stranglehold", as an EWG report put it (EWG, 2009). Meanwhile, consumers were unaware of externalities associated with ubiquitous compounds and therefore could not act as even a secondary safeguard to enforce cooperation. While TSCA failed to address ownership with new chemicals, a larger failure persisted through existing compounds. TSCA permitted the review of as many as 50 existing chemicals per year. Yet during the first 15 years of TSCA's existence, the EPA required industry testing for 25 chemicals, voluntary testing for another 34 chemicals, and proposed testing for 8 more, far short of the annual allotment of 50 chemicals (Koch & Ashford, 2006).

Driven by perceived benefits, a key characteristic of disruptive technologies, flame retardants achieved ubiquity long before TSCA was implemented. Yet flame retardants were not targeted by the agency until 2006's SNURs for penta- and octa-BDE. While the goal of adaptive policy is to avoid the stifling of markets, policies need to walk the fine line of promoting innovation while limiting externalities. TSCA was theoretically designed to empower the EPA to limit externalities by exercising control over what was reviewed and subsequently restricted. Yet the EPA's inability to identify flame retardants as a target for restriction demonstrated TSCA's failure to establish a system of externality control, a function requiring more than toxicology testing within an initial risk assessment. For example, flame retardants' aggregate or cumulative exposure in conjunction with other similarly ubiquitous compounds should have been an important consideration for understanding the full scope of their externalities. TSCA neither required aggregate exposure testing, nor provided guidance with respect to how this sort of testing would be used within a regulatory framework (Schierow, 2008).

Limiting information asymmetry through upstream cooperation requires shared access to information. One of TSCA's primary goals was to expand the EPA's chemicals database by requiring PNMs for every new chemical entering the market. Despite improving the pool of information for regulators thus reducing information asymmetry, TSCA did not require industry to participate in the process of externality control beyond receiving approval for production and distribution, much less to publicize related findings. A lack of access to relevant data and information prevented the broader epistemic community – including independent experts and consumer advocates – from exerting any amount of control.

Adaptive governance would assume the scope of cooperation to shift or expand as a function of impacts society and the environment. For flame retardants, the lack of scientific awareness for long-term effects limited the initial scope of stakeholder involvement. While the socio-technical system of chemical policy grew with advances in environmental and biomarker monitoring to include some consumer-focused groups, the first thirty years of TSCA saw flame retardants receive little notice from non-industry stakeholders. Additionally, there existed little incentive to conduct backwards-looking reviews for a technology that so effectively solved the challenges of flammability. A policy lacking the ability to look past the perceived benefits of an emerging disruptive technology will inherently hamper the emergence of a future-regarding adaptive governance system.

Breakdown 3: Failure to support continuous data collection.

TSCA's PNM system was an early attempt at embedding continuous data collection within the United States' first meaningful attempt at an all-encompassing chemical policy. Additionally, granting the EPA the ability to review existing chemicals added a backwards-looking component to this system. However, these potentially adaptive mechanisms suffered from the previously discussed failures to consider new inputs and outcomes (Breakdown 1) and to enforce ownership, control, and responsibility (Breakdown 2), failures that were further compounded by a lack of continuous data collection. This failure was induced by the governing bodies' inability and unwillingness to fully utilize their insights and research capabilities on two key fronts: to proactively scrutinize existing chemicals for toxicity and to monitor bioaccumulative health outcomes.

Toxicology's initial development as a field of study began in the early 1970s and science has grown rapidly prompting the Presidential/Congressional Commission on Risk Assessment and Risk Management to recommend in 1997 that TSCA receive an update to account for advances in toxicology (Schierow, 2008). The Commission identified TSCA's inability to account for the variety of metabolic processes leading to toxicity, including the difficulty associated with proving an individual chemical's contribution towards a certain case response in a world full of ubiquitous chemicals (Schierow, 2008). Flame retardants largely escaped notice as a specific contributor to a variety of negative health outcomes until the late 1990s. A greater emphasis on continuous learning may have contributed to earlier identification of the problem had the EPA under TSCA supported the study of existing chemicals by directly encouraging their routine re-examination. Flame retardants, as a highly ubiquitous compound, deserved reevaluation despite the lack of scientific evidence for their associated harms available at the time.

The PNM submission process created an upstream data and information funnel for the EPA to limit the manufacture and distribution of toxic chemicals. The EPA, however, was not meaningfully abreast of the development of new chemicals, much less engaged in pathways to share data "early and often". Koch and Ashford (2006) described the collection of risk-relevant information as the first sequential step of the chemicals risk management process. Yet, the EPA only received this information after new chemicals were developed and, thereafter, engaged with it to a limited degree. At a 1994 Senate Subcommittee on Toxic Substances, Research and Development hearing, former EPA Assistant Administrator Lynn Goldman testified, "It's almost as if [...] we have to, first, prove that chemicals are risky before we can have the testing done to show whether or not the chemicals are risky" (103rd Congress, 1994). This failure of continuous data gathering and sharing during the chemicals development process critically undermined the TSCA's adaptive potential, including its ability to nudge the centralizing chemical market towards the development of safer alternatives faster, much less to question their necessity. If anything, the combined failure to scrutinize existing chemicals while prolonging the approval of new ones through a sequential rather than cooperative data gathering process locked in place progress towards safer and more effective flame-retardant technology.

Many classes of flame retardants existed before TSCA and thus escaped the PNM funnel altogether. Brominated flame retardants were not restricted under SNURs at a national level for nearly four decades despite significant improvements in biomonitoring research during the 1980s (Bernard & Lauwerys, 1986). The environmental science community did not apply biomonitoring techniques to brominated flame retardants until the late 1990s, despite U.S. production of bromine reaching 229,000 tons in 2000, the world's largest (Alaee et al., 2003). Brominated flame retardants were a readily available and inexpensive panacea against the problem of flammability. However, adaptive policies can look past perceived benefits and apply updated best available practices to existing technologies.

Breakdown 4: Failure to foster policy learning through an independent assessment system (among other things).

The benefits of adaptive governance systems rest on the premise that policy change and learning is built into the policy itself. Yet, while TSCA painted relatively broad lanes within which policy learning could have emerged, neither the industry nor its regulators were committed to harnessing that potential. Several counterfactual observations can serve as proof:

- TSCA proved unable to establish a baseline that would allow for the informed monitoring of bioaccumulative effects and health outcomes. Similarly, it proved incapable of recognizing the emerging prevalence of lifecycle analyses (LCAs). This failure is particularly damning when it comes to flame retardants because of their shapeshifting nature throughout its lifecycle, from a compound applied to or built into a product, to one that degrades and enters the air and living organisms, to one that accumulates persistently in the environment following fires and firefighting activity, to residues that – via air, soil, and water systems – spread throughout the food chain.

- TSCA and its associated upstream coordination and continuous data gathering mechanisms missed mounting and accelerating state-level regulatory pressure against the ubiquity of flame retardants in consumer products and towards a fundamental questioning of the technology itself. Focused on the chemicals themselves it could not inform the regulatory underpinnings of both market and government failures that caused the flame retardant "overmedication", such as California's Smolder Test on which flammability standards rest.

- Although capable of detecting significant shifts in use, TSCA missed the trend away from the mass-production of large quantities of flame-retardant chemicals applied to and incorporated into a wide range of products towards the development of material- and product-specific custom-crafted chemical (and nanotechnological) solutions. Much less did it prove capable of informing or monitoring that development.

- TSCA lacks touchpoints with adjacent socio-technical systems that could inform or, conversely, pick up on the development of wholesale alternatives to chemical flame-retardant technologies.

An independent and agile assessment system may be to blame for that: TSCA encouraged a degree of independent assessment within its mandate to evaluate existing chemicals. Established by TSCA Section 4 (e), the responsibilities of the Interagency Testing Committee (ITC) include the preparation of a Priority Testing List under the consideration of eight "statutory factors" that included toxicity and exposure data. Additionally, the ITC was directed to determine testing order for identified chemicals of concern. The ITC represented 14 U.S. government member organizations and delivered their recommendations to the EPA Administrator biannually. After the passage of TSCA, the ITC provided recommendations based on chemicals which member organizations identified as compounds of concern, absent a yet to establish inventory on which the ITC could rely (Gorsuch & Ingersoll, 1993). To the extent existing chemicals were a target at all, the ITC subsequently relied on the EPA's inventory of existing chemicals for screening and recommendation, for which it had to rely on industry-produced data and EPA's limited risk-assessment activities. TSCA did not, however, direct the EPA to seek unbiased independent assessment to verify agency testing results. Third-party assessment could have reduced the Type I and Type II errors benefiting both government and industry. Yet, the independently verified correctness and completeness of risk information produced by manufacturers correlate directly with the capacity of the regulator and external stakeholders to audit the information and, on its basis, induce needed policy change and learning.

Brominated flame retardants, the first classification of flame retardant to be restricted at a national-level, received national attention after the establishment of state-level regulations (Cordner, 2016). Furthermore, research to identify brominated flame retardants as endocrine disruptors, among other health concerns, was conducted independently. The inability to keep pace with state-level regulations and independent third-party assessments displayed TSCA and the EPA's lack of concurrence with best available practices and reflected the policy's lack of adaptiveness.

Lessons Learned (about the Lautenberg Amendment)

The 2016 Lautenberg Amendment to TSCA can be understood as an effort to bolster the adaptiveness of governing flame retardants, as the most directly and most extensively affected class of chemicals by this reform. The following preliminary considerations spell only cautious optimism that a more adaptive regime may emerge that would not be equally overwhelmed by disruptive technologies:

Breakdown 1 focuses on the failure to recognize increasing or shifting complexity in the socio-technical system through interdisciplinarity, thereby compromising the ability to challenge existing governance mechanisms and pay attention to new inputs and formerly unknown outcomes.

The Lautenberg Amendment's TSCA reform increased the bandwidth to test new chemicals, to do so on an enforceable timeline, and to pay heightened and primary attention to environmental and human health risks. By focusing the EPA's attention on risks posed to human health and the environment, while eliminating its considerations of costs and the requirement to find a "least burdensome" solution, the revised regime can remain focused on new chemicals' toxicity and potential health risks.

With its attention still closely trained at the evaluation of new (and to some degree pre-existing) chemicals, the revised Act is unlikely to shift (interdisciplinary) attention to new inputs, such as new social and economic practices that may call into question a chemical's use and usefulness.

Breakdown 2 focuses on the failure to compel coordination through ownership, control, and shared responsibility, thereby limiting the ability to effectively reduce information asymmetry through upstream coordination. This not only prevents the early detection of externalities but also curtails opportunities for (equally disruptive) innovation.

Several dynamics significantly increase the need for coordination and the incentives to coordinate proactively: Most importantly, the EPA must prohibit or impose restrictions against known or suspected risks. The EPA also has wider latitude to find grounds for such restrictions, namely when insufficient information is available, or when unreasonably risks are determined, or when large amounts of a chemical are produced. In addition, there are fewer mechanisms by which existing chemicals can escape scrutiny. It remains to be seen whether the enforceable deadlines imposed on the stepwise consideration of up to 85'000 chemicals will not simply overwhelm the process and open it up to legal challenges resulting in the continued unfettered use of many existing chemicals, including toxic ones.

Overall, increased regulatory scrutiny, stringency, and coerciveness should provide incentives for genuine cooperation that could benefit the industry and the regulator. There is, however, still little built-in transparency and potential for public pressure to compel as much when such cooperation is faltering (see Breakdown 3). Neither is there a ready reason to assume the reform will somehow facilitate competition among chemical manufacturers towards developing innovative and less toxic alternatives to the existing spectrum of flame retardants. But increased consumer awareness, pressure from retailers, and adjacent regulatory developments may foster innovation, which the revised regime is less likely to stifle.

Breakdown 3 focuses on the failure to support continuous data collection, as not only another contributor to reducing information asymmetry but also as a means to increase the rapid adaptiveness of existing information systems and prevailing governing mechanisms.

The data and information collection mechanisms remain largely intact. The EPA's inventory of existing chemicals is expected to undergo a "reset", whereby EPA is asked to distinguish between active and inactive chemicals. EPA can now do so without a debilitating cap on the number of existing chemicals to be scrutinized, but considering it never developed the bandwidth to reach that allotment, data collection may not truly change. What could induce incremental change, however, is the fact that “EPA can require testing or issue an order to get additional data” (Schmidt, 2016: 185). What could also result in continuously making more and better, especially environmental and health-related, data available is the involvement of a wider range of experts in the Scientific Advisory Committee on Chemicals (SACC) (EPA, n.d.).

Breakdown 4 focuses on the failure to foster policy learning through an independent assessment system (among other things), one that ensures that novel developments in adjacent socio-technical systems are considered.

Even as reformed by the 2016 Lautenberg Amendment, TSCA’s processes for both new and existing chemicals are likely to remain largely blind to the broader policy shifts induced by policy learning. It is possible that the wider and more independent scope of the Scientific Advisory Committee on Chemicals (SACC), in conjunction with the public’s input on its composition, may give voice to extra-systemic considerations and thus pick up on adaptive shifts in adjacent policy areas at all levels of government. However, to tell from its composition, that Committee remains largely focused on environmental and health impact considerations. It does not readily appear to involve experts involved in the socio-economic analysis of adjacent systems, such as international governance agreements, product standards and labeling, or – as would be relevant in the case of flame retardants, as many other additives – experts trained in social and economic behaviors.

This paper set out to examine the challenges that “disruptive technologies” pose for adaptive governance. The challenges result from such developments’ exponential growth and propagation, which notoriously outpaces regulatory scrutiny of associated risks. Not only that, inherent in such technological disruptions are market failures associated with the internal and external dynamics of affected industries: internally, they turn to focusing on managing soon consolidating technology; and, externally, they see their diminished competition while their market share increase. Both eventually lead to a reluctance to continue innovating. Adaptive governance – resting on the tenets of challenging the narrow boundaries of socio-technical systems, limiting information asymmetry through upstream engagement, learning through continuous data collection, and reshaping policies through built-in corrective mechanisms – promises effective solutions but is itself prone to breakdowns, especially so when it comes to disruptive technologies.

The advent and rapid spread of fire-retardant chemicals throughout the 1950s and 1960s, followed, in the 1970s, by a regulatory regime (in the form of TSCA) ostensibly designed to cope and grow with such developments, supplies an educative case in point because it illustrates several notorious breakdowns to which adaptive governance may succumb. Recent efforts to improve TSCA's adaptiveness now offer a comparative reference point to examine critical changes to such (quasi-)adaptive regimes in order to gauge their success in performing the critical functions we wish for them to deliver in terms of offering an evolving balance between managing risks and encoraging continued innovation.

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