HERDING CATS: GOVERNING DISTRIBUTED INNOVATION*

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Do-It-Yourself biology, 3D printing, and the sharing economy are equipping ordinary people with new powers to shape their biological, physical, and social environments. This phenomenon of distributed innovation is yielding new goods and services, greater economic productivity, and new opportunities for fulfillment. Distributed innovation also brings new environmental, health, and security risks that demand oversight, yet conventional government regulation may be poorly suited to address these risks. Dispersed and dynamic, distributed innovation requires the development of more flexible tools for oversight and government collaboration with private partners in governance.

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INTRODUCTION

Various technological advances are equipping ordinary people with new powers to shape their biological, physical, and social environments. Do-It-Yourself biology ("DIYbio") offers amateur biotechnologists the chance to design new organisms. 3D printing enables individuals to design and manufacture a confounding array of objects. The sharing economy—and the technological changes behind it—facilitate constant innovation in providing goods, services, and information outside of traditional managerial hierarchies. On top of these advances, the internet enables rapid and widespread diffusion of each of these technologies. DIYbio, 3D printing, and the sharing economy are examples of "distributed technologies": technologies in which a wide range of users may participate in the innovation process. Distributed technologies are transforming how we live and interact, dispersing the innovation process, and giving individuals the power to invent, produce, and disseminate.

The resulting changes can give rise to new products and services and new means of production. They may also offer environmental benefits by increasing efficiency or reducing waste. At the same time, distributed-innovation activities can generate new risks of chemical exposure or environmental release. Distributed-innovation activities may also circumvent legal protections or involve deliberate misuse.

Normally, command-and-control regulation, market-based mechanisms, or other regulatory techniques could be applied to manage health and environmental risks. Distributed-innovation practices, however, often lie outside the ambit of these methods as currently deployed. In many instances it will be difficult, if not impossible, to apply conventional risk management to distributed-innovation activities because of their dispersed and dynamic nature. Such difficulty raises questions regarding government's ability to modify its methods or adopt new regulatory approaches in response. Society may need to look beyond regulation for tools to help manage risks.

Scholarship that considers environmentally harmful individual behavior provides a useful starting point for thinking about how to manage the risks of distributed innovation. Tactics to influence individual behavior, however, may not apply directly to distributed innovation. Distributed innovation involves extremely rapid change, unpredictable systems, and highly uncertain effects. This Article explains how distributed innovation poses an increasingly important challenge for regulators and then identifies potential mechanisms for managing its risks.

Part I of the Article introduces three examples of distributed innovation—DIYbio, 3D printing, and the sharing economy—and describes associated concerns that may warrant oversight. While these examples build on different technological advances, they are all characterized by decentralized problem solving, participation by dispersed actors, and dynamic change. Part II explores the challenges that distributed innovation poses for conventional regulatory techniques. Distributed innovation looks quite different from the concentrated industrial or commercial activities typically governed by the regulatory state. For insights into responding to the challenges posed by distributed innovation, Part III turns to prior and existing efforts to address environmental harms resulting from small-scale or individual behavior. Building on these insights, Part IV returns to the challenges posed by distributed innovation and suggests a paradigm for organizing options for governance. Specifically, distributed-innovation governance might take one of three general approaches: (1) a "Big Data/Big Government" approach; (2) an approach that relies heavily on nongovernmental intermediaries for oversight; and (3) a self-regulatory approach. Yet no single approach offers a complete response to distributed innovation's risks. Part V explores how society might apply these various approaches to DIYbio, 3D printing, and the sharing economy. Ultimately, each approach may have a distinct role to play in the governance of different fields of distributed innovation.

I. THREE EXAMPLES OF DISTRIBUTED INNOVATION

Distributed innovation describes processes in which "users of products and services—both firms and individual consumers—are increasingly able to innovate for themselves."[1] Such a system is "characterized by decentralized problem solving, self-selected participation, self-organizing coordination and collaboration, 'free' revealing of knowledge, and hybrid organizational models that blend community with commercial success."[2] Several of distributed innovation's features—decentralization, wide dissemination, and collaborative work—promise to spur creativity and bring about transformative change. At the same time, distributed innovation breaks with conventional models of economic activity and assumptions regarding risk generation, raising new challenges for regulators. This Part considers three examples of distributed innovation: DIYbio, 3D printing, and the sharing economy. In each

1. ERIC VON HIPPEL, DEMOCRATIZING INNOVATION 1 (2005) (describing distributed innovation as innovation that is "democratized"). Jennifer Snow uses a similar term, "Radical Leveling Technology," to refer to disruptive technologies that can be diffused over the internet and require minimal infrastructure or investment. Jennifer J. Snow, Entering the Matrix: The Challenge of Regulating Radical Leveling Technologies, at 3 (Dec. 2015) (unpublished M.S. thesis, Naval Postgraduate School), http://calhoun.nps.edu/bitstream/handle/10945/47874/15Dec_Snow_Jennifer.pdf?sequence=3&isAllowed=y [https://perma.cc/US6G-A6SU].

2. Karim R. Lakhani & Jill A. Panetta, *The Principles of Distributed Innovation*, 2 INNOVATIONS: TECH., GOVERNANCE, GLOBALIZATION 97, 98 (2007).

instance, diminishing entry barriers to cutting-edge technologies have enabled more and more people to engage in the innovation process.[3]

A. DIYbio

DIYbio refers to biotechnology research conducted by scientists and non-scientists outside of traditional academic and industrial institutions.[4] This research is often aimed at encouraging collaboration and experimentation without specialists providing direct assistance.[5] DIYbio experiments might take place in community labs (dedicated labs with pooled resources where people collaborate on science projects) or private homes.[6] Setting up a DIYbio lab in one's garage might cost a few thousand dollars, or less if one uses secondhand or improvised equipment.[7] Community labs, an increasingly popular DIYbio venue, offer classes, sharing of expertise, and access to more powerful equipment at a lower per capita cost.[8] The shrinking of economic, institutional, and educational barriers to entry has broadened participation in biotechnology research, a realm that previously required technical expertise and expensive equipment.[9] The core premise of DIYbio, consistent with the citizen science movement of which it is a part, is that amateurs should enjoy the freedom to learn basic biotechnology techniques and

3. *See* Andrew D. Maynard, *Why We Need Risk Innovation*, 10 NATURE NANOTECHNOLOGY 730, 730–31 (2015).

4. *See* DANIEL GRUSHKIN, TODD KUIKEN & PIERS MILLET, WILSON CTR., SEVEN MYTHS & REALITIES ABOUT DO-IT-YOURSELF BIOLOGY 4 (2013). This Article uses the term "DIYbio" to refer generally to biotechnology research conducted outside of traditional academic and industrial institutions. DIYbio.org is the largest organization engaged in such activity. Catherine Jefferson, *The Growth of Amateur Biology: A Dual Use Governance Challenge?* 3 (Biochemical Security 2030 Project, Policy Paper 3, 2013), https://biochemsec2030dotorg.files.wordpress.com/2013/08/jefferson-policy-paper-3-for-print.pdf [https://perma.cc/457D-TN5J]; *see also An Institution for the Do-It-Yourself Biologist*, DIYBIO, https://diybio.org/ [https://perma.cc/A9C4-WSX4].

5. Thomas Landrain et al., *Do-It-Yourself Biology: Challenges and Promises for an Open Science and Technology Movement*, 7 SYST. SYNTHETIC BIOLOGY 115, 116 (2013).

6. GRUSHKIN ET AL., *supra* note 4, at 5.

7. *See* Heidi Ledford, *Life Hackers*, 467 NATURE 650, 651 (2010).

8. *See id.*; *see also* GRUSHKIN ET AL., *supra* note 4, at 5, 9 (reporting survey results finding that most DIYbio practitioners work in group spaces and that just eight percent of "respondents[] work[ed] exclusively in home labs"); Ellen Jorgensen, Opinion, *How DIY Bio-Hackers Are Changing the Conversation Around Genetic Engineering*, WASH. POST (May 20, 2016), https://www.washingtonpost.com/news/in-theory/wp/2016/05/20/how-diy-bio-hackers-are-changing-the-conversation-around-genetic-engineering/ [https://perma.cc/WM6H-37MK (dark archive)] (reporting the existence of nearly thirty community labs).

9. *See* Sarah Kellogg, *The Rise of DIY Scientists: Is It Time for Regulation?*, WASH. LAW, May 2012, at 21, 22.

then use those techniques to experiment, tinker with DNA, and develop new organisms.[10]

DIYbio capitalizes on the rapidly advancing techniques of synthetic biology, which aims to design novel genetic sequences and biological systems. In contrast to conventional genetic engineering, which transplants existing genes for a desired trait from one species into the genome of another species, synthetic biology involves the writing of new genetic sequences and potentially the creation of new species.[11] Drawing on the tools and methodologies of molecular biology, computer engineering, mathematics, and other disciplines, synthetic biologists view genetic sequences as combinable and reusable parts that can be assembled to create new functionalities or new organisms.[12] Although DNA sequencing and synthesizing technologies have advanced rapidly in recent years, synthetic biologists still face difficult challenges in understanding what different genetic sequences do and how they will act when put together.[13] Nonetheless, synthetic biologists are proving increasingly adept at generating clusters of genes that can be inserted into existing species using conventional techniques.[14] Moreover, the discovery of new tools is enabling faster and more accurate gene manipulation. CRISPR-Cas9, a recently developed gene-editing technique, has sparked especially strong interest because of its speed, efficiency, and low cost.[15]

10. *See* GRUSHKIN ET AL., *supra* note 4, at 4.

11. Josie Garthwaite, *Beyond GMOs: The Rise of Synthetic Biology*, ATLANTIC (Sept. 25, 2014), http://www.theatlantic.com/technology/archive/2014/09/beyond-gmos-the-rise-of-synthetic-biology/380770/ [https://perma.cc/P8EL-XK9Y].

12. *See* Roberta Kwok, *Five Hard Truths for Synthetic Biology*, 463 NATURE 288, 288 (2010).

13. *See id.* at 288–89; *see also* Catherine Jefferson, Filippa Lentzos & Claire Marris, *Synthetic Biology and Biosecurity: Challenging the "Myths,"* FRONTIERS PUB. HEALTH, Aug. 21, 2014, at 1, 8 https://www.frontiersin.org/articles/10.3389/fpubh.2014.00115/full [perma.cc/VS4P-3K6U] (discussing challenges involved in assembling gene-length fragments and producing desired gene expression).

14. Garthwaite, *supra* note 11.

15. *See* Heidi Ledford, *Biohackers Gear Up for Genome Editing*, 524 NATURE 398, 398 (2015) [hereinafter Ledford, *Biohackers*] (reporting biohacker's characterization of CRISPR as "the most amazing tool ever"); *see also* Henry T. Greely, *Take Care!*, *in* Patrick Skerrett, *Is Do-It-Yourself CRISPR as Scary as it Sounds?*, STAT (Mar. 14, 2016), https://www.statnews.com/2016/03/14/crispr-do-it-yourself/ [https://perma.cc/U8WF-ATJR] (contending that "CRISPR is revolutionizing genetics" and that "[i]n theory, anyone can use CRISPR to modify the genes of any living organism"); Ellen Jorgensen, *DIY Community Can Do Interesting, Useful, Perfectly Respectable Things with CRISPR*, *in* Skerrett, *supra* (describing intense interest in CRISPR within the DIYbio community, including among bioentrepreneurs and artists). *See generally* Heidi Ledford, *CRISPR, the Disruptor*, 522 NATURE 20 (2015) ("CRISPR is causing a major upheaval in biomedical

For DIYbio, the tools, standardization, and modularization of synthetic biology allow a wide range of non-experts to participate in biotechnological innovation.[16] Many DIY biologists engage in rudimentary experiments that pose little risk or groundbreaking potential, and they often must develop specialized skills and knowledge to overcome technical difficulties.[17] Nevertheless, their capabilities are improving, and the activities of do-it-yourselfers cannot be ignored in light of the technology's increasing power and accessibility.

Practitioners of DIYbio sometimes label themselves "biohackers," drawing comparisons to the Silicon Valley hobbyists and inventors who initiated the digital revolution in the 1970s.[18] Like their Silicon Valley counterparts, many DIY biologists believe their efforts could lead to new insights and breakthroughs.[19] Other DIY biologists approach genetic manipulation as a way to produce art.[20] Like the open-source software movement, DIYbio emphasizes transparency and relies on the open exchange of information, materials, and publications.[21] The application of crowdfunding techniques to DIYbio further amplifies the potential spread of DIYbio activity.[22]

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research. Unlike other gene-editing methods, it is cheap, quick and easy to use, and it has swept through labs around the world as a result.").

16. *See* Todd Kuiken, *Learn from DIY Biologists*, 531 NATURE 167, 167 (2016) (noting how high school students and users of community labs participating in the 2015 International Genetically Engineered Machine competition used "[starting] kits contain[ing] more than 1,000 standard biological parts . . . need[ed] to engineer a biological system"); Landrain et al., *supra* note 5, at 116 ("As these promising biological technologies become easier to manipulate, achievements, such as plasmid refactoring, that were once only possible in leading laboratories are becoming routine for undergraduates, high school students, and even amateur biologists (that is, biologists who practice science as a 'hobby', usually outside of scientific institutions).").

17. Jefferson et al., *supra* note 13, at 3–5; *see also* ALESSANDRO DELFANTI, BIOHACKERS: THE POLITICS OF OPEN SCIENCE 115 (2013); Ledford, *Biohackers*, *supra* note 15, at 399; Jefferson, *supra* note 4, at 4.

18. *See* Ledford, *supra* note 7, at 650–51. For more examples of biohackers and their goals, see Seth Bannon, *Biotech in the Garage*, CLIMB HIGHER (July 6, 2015), http://sethbannon.com/biotech-in-the-garage [https://perma.cc/4KXP-FHWC] and Marcus Wohlsen, *Cow Milk Without the Cow Is Coming to Change Food Forever*, WIRED (Apr. 15, 2015), http://www.wired.com/2015/04/diy-biotech-vegan-cheese/ [https://perma.cc/ND4Q-BUV3].

19. *See* Landrain et al., *supra* note 5, at 118.

20. *See* R. Alta Charo & Henry T. Greely, *CRISPR Critters and CRISPR Cracks*, 15 AM. J. BIOETHICS 11, 13 (2015) (noting that "[b]ioart" already exists and speculating on efforts to produce "dwarf elephants, giant guinea pigs, or genetically tamed tigers").

21. GRUSHKIN ET AL., *supra* note 4, at 8; Ledford, *supra* note 7, at 651.

22. *See* Kuiken, *supra* note 16, at 168 (noting that synthetic biologist Josiah Zayner raised over $62,000 online to fund the production and distribution of DIY CRISPR kits).

In one of the best-known DIYbio projects to date, three hobbyists created a bioluminescent plant and formed Glowing Plant, Inc., a start-up company, to promote it.[23] Glowing Plant raised nearly half a million dollars through a crowdfunding campaign that promised seeds of the genetically altered plant to financial supporters.[24] The fact that the plant is related to a weed led to concerns that unhindered dissemination could lead to the exchange of genes with wild relatives and ecological disruption.[25] Yet no mechanism for regulatory oversight appeared applicable, as the federal agency responsible for regulating plant pests concluded that it lacked regulatory jurisdiction over the plant.[26] The Glowing Plant incident may be a harbinger of things to come. In the future, CRISPR-Cas9 and other gene manipulation techniques could allow individuals to rapidly alter the genomes of mosquitoes, weeds, or other organisms—whether deliberately or not.[27]

DIYbio raises non-ecological concerns as well. In the lab, DIY biologists may fail to heed basic safety precautions that trained scientists routinely follow and may suffer hazardous chemical exposures.[28] Moreover, using gene sequences ordered online, DIYbio practitioners could reconstruct the DNA of harmful viruses and microorganisms, a possibility that attracted the FBI's attention.[29] However, assurances from biotechnology experts that "mere knowledge of a viral genome is far from sufficient to be able to re-constitute it or to create a disease-forming pathogen" eased initial fears that bioterrorism could arise from DIYbio activity.[30] DIYbio

23. Beth Baker, *DIYbio—Alternative Career Path for Biologists?*, 65 BIOSCIENCE 112, 112 (2015); Lisa M. Krieger, *Bay Area: Tech Business' Project About Much More than Glowing Plant*, MERCURY NEWS (Aug. 18, 2013), http://www.mercurynews.com/ci_23889241/gene-engineers-popular-glow-dark-plant-tests-less [https://perma.cc/YY9T-PRYQ].

24. Krieger, *supra* note 23. The company, since renamed Taxa Biotechnologies, Inc., has yet to produce a plant that produces much glow or to ship any seeds to backers. *See* Antonio Regalado, *Why Kickstarter's Glowing Plant Left Backers in the Dark*, MIT TECH. REV. (July 15, 2016), https://www.technologyreview.com/s/601884/why-kickstarters-glowing-plant-left-backers-in-the-dark/ [https://perma.cc/4YZQ-EWCN].

25. Krieger, *supra* note 23.

26. LYNN L. BERGESON ET AL., WILSON CTR., THE DNA OF THE U.S. REGULATORY SYSTEM: ARE WE GETTING IT RIGHT FOR SYNTHETIC BIOLOGY? 45–46 (2015) (reporting the Animal and Plant Health Inspection Service's conclusion that it lacked jurisdiction because the engineered plants involve no plant pests).

27. Greely, *supra* note 15.

28. *See* Dustin T. Holloway, *Regulating Amateurs*, SCIENTIST, March 2013, 27, 28.

29. Ledford, *supra* note 7, at 651–52.

30. PRESIDENTIAL COMM'N FOR THE STUDY OF BIOETHICAL ISSUES, NEW DIRECTIONS: THE ETHICS OF SYNTHETIC BIOLOGY AND EMERGING TECHNOLOGIES 72 (2010) (noting that one must also have an appropriate host and conditions for a virus to grow); *see also* GRUSHKIN ET AL., *supra* note 4, at 10 (reporting survey results finding that

presently poses a minimal bioterrorism threat, as terrorists have other available weapons that are proven, more readily available, and easier to deploy.[31] Moreover, most DIY biologists "work in community spaces that require BSL-1 lab conditions,"[32] which means that experiments involve "well-characterized agents not known to consistently cause disease in immunocompetent adult humans, and present minimal potential hazard to laboratory personnel and the environment."[33] Nonetheless, the FBI has maintained a "neighborhood watch" approach that "relies on biohackers monitoring their own community and reporting behaviour they find threatening."[34]

B. 3D Printing

3D printing, also known as additive manufacturing,[35] offers another instance of distributed innovation that warrants society's attention. Working from computer design files, 3D printing manufactures three-dimensional objects by building up or binding multiple thin layers of plastics, metals, or other materials.[36] 3D printing's ability to produce complex items in one piece offers advantages in terms of structural integrity, weight, and waste reduction.[37]

3D-printing technology itself is not new, as engineers have used it for decades to create prototypes.[38] In recent years, advances in computing power, software, and materials have broadly expanded its use by small businesses, entrepreneurs, and hobbyists.[39] 3D printing now enables ordinary people to create complex custom objects more

most DIY biologists are "still learning basic biotechnology" and work with low-risk organisms).

31. *See* Filippa Lentzos, *Don't Single Out the DIY Community*, *in* Skerrett, *supra* note 15.

32. *See* GRUSHKIN ET AL., *supra* note 4, at 15.

33. CTRS. FOR DISEASE CONTROL & PREVENTION, BIOSAFETY IN MICROBIOLOGICAL AND BIOMEDICAL LABORATORIES 30 (5th ed. 2009).

34. Ledford, *supra* note 7, at 652; *see also* Sara Tocchetti & Sara Angeli Aguiton, *Is an FBI Agent a DIY Biologist Like Any Other? A Cultural Analysis of a Biosecurity Risk*, 40 SCI., TECH., & HUM. VALUES 825, 829 (2015) (discussing the formation of a working relationship between the FBI and the DIYbio community).

35. HOD LIPSON & MELBA KURMAN, FABRICATED: THE NEW WORLD OF 3D PRINTING 65 (2013).

36. *See id.* at 65–84; Lucas Osborn, *Regulating Three-Dimensional Printing: The Converging Worlds of Bits and Atoms*, 51 SAN DIEGO L. REV. 553, 558–59 (2014).

37. *See* Snow, *supra* note 1, at 20.

38. Robert Olson, *A Boon or a Bane?*, ENVTL. F., Nov./Dec. 2013, at 34, 35.

39. *See* LIPSON & KURMAN, *supra* note 35, at 11.

quickly, cheaply, and skillfully than was previously possible.[40] Individuals can purchase their own 3D printers, access a 3D printer in a communal workspace, or use online services to print objects.[41] A wide range of objects can be printed, including guns, food, body parts, and living tissue.[42] Perhaps the most significant constraints on 3D printing today are its slow speed—which is dictated in part by the time it takes for material to harden—and its inability to print with materials that have dissimilar melting points.[43]

Like DIYbio, 3D printing enables individuals to engage in innovative activities that, because of their cost and complexity, were previously limited to institutional actors.[44] Both DIYbio and 3D printing are subcategories of the maker movement, which refers to a broad range of inventors, designers, and tinkerers who are engaged in making things themselves, whether for fun or profit.[45] Used by many maker enthusiasts, 3D printing is a "broad platform technology" that could change manufacturing practices, facilitate technological breakthroughs, and transform society.[46]

3D printing may raise several concerns for policymakers, however. First, the 3D-printing process can have adverse health or environmental effects. 3D printing may involve the use of toxic or explosive substances.[47] Operating 3D printers may lead to chemical respiratory exposures comparable to indoor smoking, causing headaches, nausea, and severe skin and eye irritation.[48] In commercial

40. *See id.* at 20–24, 30–33.

41. *See* John Schryber & Farah Tabibkhoei, *Insurance Issues*, *in* REED SMITH, 3D PRINTING OF MEDICAL DEVICES 22, 22 (Colleen Davies et al. eds., 2015), https://www.reedsmith.com/files/Publication/130448b9-7565-4295-a697-5c5d7c6eb516/Presentation/PublicationAttachment/9ba9b53c-2009-488d-ba91-5cc5a19a38f7/3d-printing-white-paper_79444049.pdf [https://perma.cc/9T3D-C7G8] (discussing the accessibility of 3D printers).

42. *See* Osborn, *supra* note 36, at 561; Olson, *supra* note 38, at 34–35, 38; *see also* Lisa Baird & Matthew Jacobson, *3D Printing and Its Impact on Medical Device and Health Care*, *in* 3D PRINTING OF MEDICAL DEVICES, *supra* note 41, at 4, 4–5 (discussing medical applications).

43. *See* Olson, *supra* note 38, at 35.

44. *See id.* at 34, 38 (noting how DIY biologists could use 3D printers to print their own living tissue or bacteria).

45. *See* Tim Bajarin, *Why the Maker Movement Is Important to America's Future*, TIME (May 19, 2014), http://time.com/104210/maker-faire-maker-movement/ [http://perma.cc/6Y7Y-AMBU].

46. LIPSON & KURMAN, *supra* note 35, at 50; *see also* Bajarin, *supra* note 45; Doug Gross, *Obama's Speech Highlights Rise of 3-D Printing*, CNN (Feb. 13, 2013), http://www.cnn.com/2013/02/13/tech/innovation/obama-3d-printing/ [https://perma.cc/KXE8-YD3T].

47. *See* Osborn, *supra* note 36, at 564; Olson, *supra* note 38, at 37.

48. *See* Olson, *supra* note 38, at 37.

facilities, Occupational Safety and Health Administration ("OSHA") regulations could limit worker exposures and reduce combustion risks by mandating protective equipment and practices.[49] In other environments, however, students or hobbyists engaged in 3D printing may be less familiar with potential hazards and less apt to adopt appropriate precautionary measures. Furthermore, while 3D printing is sometimes hailed as a means of reducing manufacturing waste and the need to transport goods long distances,[50] the overall environmental impact of 3D printing will depend on particular machines and materials, as well as on patterns of use.[51]

Second, 3D-printed products may warrant even greater regulatory attention. Toys and other everyday products are normally subject to industry standards and some consumer-protection requirements, however minimal.[52] Objects produced by 3D printing, in contrast, might escape conventional regulatory channels as a result of their origin or small-scale manufacture. Furthermore, 3D printing could be used for nefarious purposes: one might print counterfeit machinery parts designed to break, potentially causing catastrophic consequences.[53] Terrorists might print biological weapons, chemical weapons, or drones designed to deliver explosives or other deadly payloads.[54] 3D printing also may be used to manufacture closely

49. *Id.* at 38. Compliance with OSHA regulations may be another matter entirely, however. *See id.*; *see also* Todd Maiden & Farah Tabibkhoei, *Environmental Effects and Health Risks in the Workplace*, *in* 3D PRINTING OF MEDICAL DEVICES, *supra* note 41, at 20, 20–21 (recounting OSHA citation issued to 3D-printing company for various violations of workplace safety standards).

50. *See* Osborn, *supra* note 36, at 564–65.

51. *See* Olson, *supra* note 38, at 36–38.

52. *See, e.g.*, 15 U.S.C. § 2056(a) (2012) (authorizing promulgation of consumer product safety standards); § 2056b (establishing mandatory toy safety standards). The Consumer Product Safety Commission's effectiveness has been widely questioned. *See, e.g.*, Russell T. Gips, Comment, *From China with Lead: The Hasty Reform of the Consumer Product Safety Commission*, 46 HOUS. L. REV. 545, 547–48, 555–56 (2009) (noting widespread criticism of the Commission).

53. *See* Peter Jensen-Haxel, *3D Printers, Physical Viruses, and the Regulation of Cloud Supercomputing in the Era of Limitless Design*, 17 MINN. J.L. SCI. & TECH. 737, 767–68 (2016) (discussing how hackers will attack various weak links in the computer-aided design process at the heart of 3D printing); Kathy Wren, *Realizing the Full Benefits of 3D Printing Will Require Openness, Experts Say*, AAAS NEWS (Oct. 25, 2013), http://www.aaas.org/news/realizing-full-benefits-3d-printing-will-require-openness-experts-say [https://perma.cc/6PD9-SMTE].

54. *See Emerging Technologies: Lowering the Threshold for ISIS (Islamic State of Iraq and Syria) Mass Casualty Terrorism*, BIOLOGICAL WARFARE BLOG: BLACK SIX (July 31, 2015, 2:41 AM), http://bio-defencewarfareanalyst.blogspot.com/2015/07 [https://perma.cc/44DN-CU8J (dark archive)]; Roxanne Palmer, *3D Printing Risks: Not Just Plastic Guns, but Military Parts, Drugs and Chemical Weapons*, INT'L BUS. TIMES (May 24, 2013),

regulated items such as weapons[55] or custom-designed drugs.[56] Although plastic 3D-printed guns are subject to overheating and cracking after a few uses, such guns are difficult for security equipment to detect, can be shaped in unrecognizable forms, and could be particularly appealing to hobbyists and teenagers.[57] In addition, the quality and capabilities of printed guns are rapidly improving.[58] Fear that 3D printing would lead to the proliferation of plastic guns has led to proposals to limit or ban their production.[59] The United States Department of State has attempted to curb the online publication of digital gun files, contending that such publication could violate the International Trade in Arms regulations.[60] The ease of copying and sharing electronic files, however, may make these efforts futile.[61]

Third, by facilitating the counterfeiting of objects, 3D printing also has the potential to undermine intellectual property protections and confound the identification of persons responsible for intellectual property violations.[62] Indeed, as consumers engage more widely in

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http://www.ibtimes.com/3d-printing-risks-not-just-plastic-guns-military-parts-drugs-chemical-weapons-1275591 [http://perma.cc/BLM8-WCUF].

55. Wren, *supra* note 53 (citing examples of 3D-printed guns and "keys that can open high-security locks"); *see also* Snow, *supra* note 1, at 32 (discussing potential use of 3D printing to produce nuclear weapons components).

56. LIPSON & KURMAN, *supra* note 35, at 220–21; Snow, *supra* note 1, at 1.

57. Nick Bilton, *The Rise of 3-D Printed Guns*, N.Y. TIMES, Aug. 14, 2014, at E2. Various gun control measures, including registration and marking requirements, could readily be circumvented by printing plastic guns. DANIEL CASTRO, INFO. TECH. & INNOVATION FOUND., SHOULD GOVERNMENT REGULATE ILLICIT USES OF 3D PRINTING? 3 (2013), http://www2.itif.org/2013-regulate-illicit-3d-printing.pdf [https://perma.cc/RRP5-Q765].

58. Adam Clark Estes, *3D-Printed Guns Are Only Getting Better, and Scarier*, GIZMODO (Jan. 6, 2015), http://gizmodo.com/3d-printed-guns-are-only-getting-better-and-scarier-1677747439 [http://perma.cc/2QZS-TCTK]; *see* Rob Walker, *A Crypto-Anarchist Will Help You Build a DIY AR-15*, BLOOMBERG BUSINESSWEEK (June 22, 2016), https://www.bloomberg.com/features/2016-cody-wilson-ghost-gunner-ar-15/ [http://perma.cc/G6HW-2PVG].

59. *See, e.g.*, Undetectable Firearms Modernization Act of 2015, H.R. 2699, 114th Cong. § 2 (2015). The Undetectable Firearms Act prohibits the manufacture, distribution, or possession of guns that cannot be detected by a metal detector. 18 U.S.C. § 922(p)(1)–(6) (2012).

60. Andy Greenberg, *Feds Tighten Restrictions on 3-D Printed Gun Files Online*, WIRED (June 11, 2015), http://www.wired.com/2015/06/feds-restrict-3d-printed-gun-files/ [http://perma.cc/MB4C-WHJA].

61. *See* CASTRO, *supra* note 57, at 2.

62. *See* Deven R. Desai & Gerard N. Magliocca, *Patents, Meet Napster: 3D Printing and the Digitization of Things*, 102 GEO. L.J. 1691, 1703 (2014) (contending that "3D printing brings the problems of digitization to patents for the first time"); *see also id.* at 1713–14 (recommending that Congress create a patent infringement exception for personal 3D printing and notice-and-takedown rules for sites that host 3D-printing

copying and creating, 3D printing may weaken some of the rationales that underlie existing intellectual property regimes.[63]

C. *The Sharing Economy*

Finally, consider one other example of distributed innovation: the sharing economy. Distributed innovation in this context involves not only the sharing economy itself but also the proliferation of digital platforms that enable sharing-economy activities. Though there is no agreed-upon definition of the sharing economy, the term generally refers to a wide range of activities "in which assets or services are shared between private individuals, either free or for a fee, typically by means of the Internet."[64] At the heart of the sharing economy are digital-platform technologies that enable more intensive use of resources, whether in the form of housing stock, motor vehicles, or human labor. These platform technologies lower transaction costs and facilitate nearly instantaneous exchanges, often bypassing traditional businesses in favor of peer-to-peer transactions.[65]

software); Timothy R. Holbrook & Lucas S. Osborn, *Digital Patent Infringement in an Era of 3D Printing*, 48 U.C. DAVIS L. REV. 1319, 1325 (2015) (proposing theory of "digital patent infringement" in which creation of digital files that can directly print objects might infringe a patent claim relating to the underlying physical object). *See generally* Tabrez Y. Ebrahim, *3D Printing: Digital Infringement & Digital Regulation*, 14 NW. J. TECH. & INTELL. PROP. 37 (2016) (exploring patent law issues).

63. *See* Osborn, *supra* note 36, at 583 (suggesting that the consumer protection rationale for trademark law does not apply where consumers themselves violate trademark protections by printing a counterfeit object).

64. *Sharing Economy*, OXFORD DICTIONARY ONLINE, http://www.oxforddictionaries.com/us/definition/american_english/sharing-economy [http://perma.cc/CJH3-8Y82]; *see also* Jenny Kassan & Janelle Orsi, *The Legal Landscape of the Sharing Economy*, 27 J. ENVTL. L. & LITIG. 1, 3 (2012) (listing various collaborative practices considered to be a part of the sharing economy); DAMIEN DEMAILLY & ANNE-SOPHIE NOVEL, INST. FOR SUSTAINABLE DEV. & INT'L RELATIONS, THE SHARING ECONOMY: MAKE IT SUSTAINABLE 13–14 (2014), http://www.iddri.org/Evenements/Interventions/ST0314_DD%20ASN_sharing%20economy.pdf [https://perma.cc/YDW8-NU4J] (setting out sharing models of redistribution of goods, mutualization of goods, and shared mobility); JULIET SCHOR, GREAT TRANSITION INITIATIVE, DEBATING THE SHARING ECONOMY 2 (2014), http://www.greattransition.org/images/GTI_publications/Schor_Debating_the_Sharing_Economy.pdf [https://perma.cc/CE8J-QGRW] (describing the sharing economy as "recirculation of goods, increased utilization of durable assets, exchange of services, and sharing of productive assets"). It is worth noting that much of the activity falling under the "sharing economy" rubric does not involve actual sharing of economic resources. A perhaps more accurate account describes users of digital platforms as engaging in "shared value creation." BRHMIE BALARAM, ROYAL SOCIETY FOR THE ENCOURAGEMENT OF ARTS, MANUFACTURES & COMMERCE, FAIR SHARE: RECLAIMING POWER IN THE SHARING ECONOMY 15 (2016), https://www.thersa.org/globalassets/pdfs/reports/rsa-fair-share.pdf [https://perma.cc/5LNY-PJ58].

65. *See* Orly Lobel, *The Law of the Platform*, 101 MINN. L. REV. 87, 89–90 (2016); Noah Zon, *The Sharing Economy and Why It Matters for Policy Makers*, PUB. SECTOR

In contrast to DIYbio and 3D printing, which introduce new ways to invent and produce things, the activities that make up the sharing economy generally are not themselves new.[66] People have long offered rides, lodging, and other goods and services for exchange. However, these entrepreneurial activities are occurring through peer-to-peer exchanges on an unprecedented scale, and consequently their cumulative impacts are warranting society's attention for the first time. Through such platforms as Uber, Airbnb, and Taskrabbit, "[m]illions of people are becoming part-time entrepreneurs, disrupting established business models and entrenched market interests, and challenging regulated industries."[67]

Moreover, while sharing-economy activities themselves may not be novel, there is indeed something novel about the sharing economy itself. Capitalizing on the ubiquity of smartphones and internet connectivity, innovators are using digital-platform technologies to constantly invent new marketplaces for exchange. A leading directory lists nearly 10,000 sharing-economy companies worldwide, with more added virtually every day.[68] From a regulator's point of view, the launch of a new business may hardly be remarkable. The launch of a new marketplace, however, may be an entirely different matter worth noting.

Potential benefits of the sharing economy include greater access to goods and services, lower prices for consumers, and increased income for providers.[69] The sharing economy's rapid growth reflects strong interest on the part of both consumers and providers in reaping

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DIG., Dec. 2015, at 2, https://mowatcentre.ca/wp-content/uploads/publications/PublicSectorDigest_TheSharingEconomyandWhyitMattersforPolicyMakers.pdf [perma.cc/HZ2W-MBVD].

66. Sofia Ranchordás, *Does Sharing Mean Caring? Regulating Innovation in the Sharing Economy*, 16 MINN. J.L. SCI. & TECH. 413, 433, 456 (2015).

67. Lobel, *supra* note 65, at 90–91.

68. *Partners,* MESH, http://meshing.it/partners [perma.cc/5GMA-GAP3]; *see also Sharing Economy Startups*, ANGELLIST, https://angel.co/sharing-economy-4 [https://perma.cc/Z5DQ-C4E4].

69. *See* Ranchordás, *supra* note 66, at 466. In addition, sharing activities that do not involve direct economic exchange, such as gifting practices or tool lending, strengthen social capital by facilitating communication and cooperation. *See* Russell Belk, *Sharing*, 36 J. CONSUMER RES. 715, 717 (2010) ("Sharing . . . goes hand in hand with trust and bonding. It differs from economic exchange, which rarely creates communal bonds with other people."); *see also* JULIAN AGYEMAN, DUNCAN MCLAREN & ADRIANNE SCHAEFER-BORREGO, FRIENDS OF THE EARTH, SHARING CITIES 16-17 (2013), https://www.foe.co.uk/sites/default/files/downloads/agyeman_sharing_cities.pdf [https://perma.cc/28K2-Q5VX].

these benefits.[70] In economic terms, the sharing economy potentially addresses various market failures by increasing competition, reducing transaction costs and informational asymmetry, putting underutilized capital to use, and challenging the capture of regulatory agencies.[71]

Notwithstanding these benefits, the sharing economy also raises various concerns. Participants in sharing-economy transactions may encounter deceptive techniques, unsafe conditions, or unfair labor practices.[72] For established operators, the sharing economy represents new competition that may gain an unfair advantage by skirting traditional regulatory regimes.[73] Furthermore, sharing-economy transactions may generate a range of external effects, including decreased tax revenue for governments, increased noise and traffic for neighbors, greater burdens on infrastructure, and disrupted labor and housing markets.[74] Although the notion of "sharing" suggests less resource-intensive ways of doing things, the overall environmental impacts of the sharing economy are unclear. Not only does the sharing economy involve little *actual* sharing, but the lower prices it often brings also can foster higher levels of consumption.[75] Additionally, the technology underlying the sharing economy collects vast quantities of data, raising concerns about loss of privacy.

The large numbers of individuals participating in the sharing economy, often on a part-time basis and through evolving business models, challenge conventional models of government regulation.[76] As one commentator has remarked, "many sharing economy businesses have violated state or local government laws."[77] The law,

70. *See* Stephen R. Miller, *First Principles for Regulating the Sharing Economy*, 53 HARV. J. ON LEGIS. 147, 157 (2016).

71. Cristopher Koopman, Matthew Mitchell & Adam Thierer, *The Sharing Economy and Consumer Protection Regulation: The Case for Policy Change*, 8 J. BUS. ENTREPRENEURSHIP & L. 529, 531–32 (2015); *see also* Lobel, *supra* note 65, at 89–90.

72. *See* Miller, *supra* note 70, at 152.

73. *See* Daniel E. Rauch & David Schleicher, *Like Uber, but for Local Government Law: The Future of Local Regulation of the Sharing Economy*, 76 OHIO ST. L.J. 901, 922–23 (2015).

74. Kellen Zale, *When Everything is Small: The Regulatory Challenge of Scale in the Sharing Economy*, 53 SAN DIEGO L. REV. 949, 983–90 (2016); *see also* Lobel, *supra* note 65, at 126–38; Miller, *supra* note 70, at 169 (noting that sharing economy "harm is often uniquely challenging to determine" but also suggesting possible community harms engendered by short-term housing rentals).

75. *See* DEMAILLY & NOVEL, *supra* note 64, at 8 ("[S]haring models can either be a vector for a sustainable, less material type of consumption or, conversely, a vector for the hyperconsumption of goods."); SCHOR, *supra* note 64, at 7 ("The [sharing] platforms are creating new markets that expand the volume of commerce and boost purchasing power.").

76. *See* Lobel, *supra* note 65, at 101–02.

77. Miller, *supra* note 70, at 149.

which works through definitions, rules, and boundaries, is often poorly equipped to keep up with the sharing economy and its dynamic and distributed nature.[78]

* * *

The preceding discussion highlights leading examples of distributed innovation. DIYbio, 3D printing, and the sharing economy shift power away from government, big business, and other traditionally powerful institutions. Yet these examples are just a subset of emerging technologies that pose new governance challenges.[79] Across society, rapid technological change—whether in the form of drones, autonomous vehicles, digital currencies, or smart infrastructure—threatens to disrupt conventional regulatory models.[80] In an ever-changing environment, where individual conduct can have dramatic consequences for society, how can society govern that conduct?

II. CHALLENGES THAT DISTRIBUTED-INNOVATION TECHNOLOGIES POSE FOR REGULATORS

Distributed innovation can be a powerful force for economic growth, technological breakthroughs, and social change. Drawing on the energy and creativity of individuals to produce new products and services, distributed innovation broadens the innovation process. Furthermore, distributed innovation can offer personal fulfillment and generate income while putting underutilized human and real capital to work.[81]

Distributed innovation nonetheless warrants the attention of regulators. Participants in distributed innovation themselves may need protection, and distributed-innovation activities may have adverse consequences on non-participants as well. Oversight—broadly understood here to refer to some form of third-party intervention, governmental or otherwise—can correct market

78. *See* Lobel, *supra* note 65, at 102.

79. *See* Larry Downes, *Fewer, Faster, Smarter*, DEMOCRACY J., Fall 2015, at 3, http://democracyjournal.org/magazine/38/fewer-faster-smarter/ [https://perma.cc/JV5U-GR6G].

80. *Id.* Contemporary methods of terrorism, in which terror groups use social media to radicalize, recruit, and inspire terrorist activity in disparate locations, raise similar challenges. *See* YONAH ALEXANDER & DEAN ALEXANDER, THE ISLAMIC STATE: COMBATING THE CALIPHATE WITHOUT BORDERS 55 (2015).

81. Lakhani & Panetta, *supra* note 2, at 103–04.

failures, incentivize competition, and ensure a level playing field. Equally important, oversight can "address public safety, quality control, privacy, access, equality, fairness, and distributional concerns."[82]

This Part explores a number of reasons why distributed innovation poses particular difficulties for regulators. Law's categorical nature makes it difficult to apply to dynamic and differentiated processes. Logistical, political, and cultural barriers may hamper regulation of distributed innovation. Even further, the harms associated with distributed innovation may be difficult to identify.

A. Law's Categorical Nature

Law is often viewed as hostile to innovation. Undoubtedly, regulatory environments may involve rigid hierarchies, inflexible processes, and aversion to change.[83] Yet policymakers face the tricky task of balancing competing interests when regulating innovation. Excessive regulatory burdens can stifle innovation but so can regulatory uncertainty.[84] Well-designed laws—in tax, intellectual property, and other areas—can create incentives for innovation and foster a stable environment in which people are willing to invest efforts and resources in innovation.[85]

Law relies on the process of categorization to determine what and how behavior is governed.[86] But distributed-innovation activities often do not fit neatly within existing legal categories.[87] The sharing economy provides numerous examples of this difficulty, as legal battles rage over whether to regulate Uber drivers like taxi drivers,

82. Lobel, *supra* note 65, at 118; *see* SUNIL JOHAL & NOAH ZON, MOWAT CTR., POLICYMAKING FOR THE SHARING ECONOMY: BEYOND WHACK-A-MOLE 13 (2015), https://mowatcentre.ca/wp-content/uploads/publications/106_policymaking_for_the_sharing_economy.pdf [https://perma.cc/JMK6-5BJH] ("In many cases, unfamiliarity with sharing economy models has hindered the ability of governments to recognize potential benefits such as innovation, economic growth, and more efficient networks for urban transportation and logistics.").

83. *See* JOHAL & ZON, *supra* note 82, at 14–17.

84. Ranchordás, *supra* note 66, at 440–42.

85. *See id.* at 448; *see also* ALBERT C. LIN, PROMETHEUS REIMAGINED: TECHNOLOGY, ENVIRONMENT, AND LAW IN THE TWENTY-FIRST CENTURY 7 (2013); Gaia Bernstein, *In the Shadow of Innovation*, 31 CARDOZO L. REV. 2257, 2264–69 (2010) (summarizing debates on role of law in fostering innovation).

86. *See* Lobel, *supra* note 65, at 102 ("Law and language attempt to chart boundaries, and yet they are inherently limited in covering all forms of life and human imagination.").

87. *See* Vanessa Katz, Note, *Regulating the Sharing Economy*, 30 BERKELEY TECH. L.J. 1067, 1092 (2015); *see also* JOHAL & ZON, *supra* note 82, at 13.

whether to treat Airbnb hosts like hotel operators, and how to govern digital platforms themselves.[88] Heavy-handed attempts to apply existing laws to individual operators may chill economically productive activity or drive it underground, making it harder to track, assess, and regulate.[89]

In some instances, distributed-innovation activities may fall completely outside of existing oversight structures. Many laws were "designed for a Fordist era of mass production, where centralised entities are producing items which are then sold in shops and bought complete by consumers."[90] Regulatory regimes may exempt small-scale operators, explicitly or implicitly, because the benefit from regulating de minimis activities may not justify the effort.[91] Small-scale exemptions also can protect privacy or advance a societal interest in lowering barriers to entry.[92] Nevertheless, the key assumption underlying such exemptions—that the effects of small-scale activities do not matter—may not hold true in an increasing number of contexts.[93] Collectively, distributed-innovation activities may achieve such a scale that they can significantly affect surrounding

88. *See* Eric Biber et al., *Regulating Business Innovation as Policy Disruption: From the Model T to Airbnb*, 70 VAND. L. REV. 1561, 1581–84 (2017) (discussing policy disruptions fueled by business innovation). California, for example, has established a regulatory system to govern Lyft, UberX, and other "transportation network companies," a term defined to include "an organization . . . that provides prearranged transportation services for compensation using an online-enabled application (app) or platform to connect passengers with drivers using their personal vehicles." Decision Adopting Rules and Regulations to Protect Public Safety While Allowing New Entrants to the Transportation Industry at 2, Decision No. 13-09-045, Rulemaking No. 12-12-011 (Cal. Pub. Utils. Comm'n Sept. 19, 2013), 2013 WL 10230598, at *1; *see* Sarah E. Light, *Precautionary Federalism and the Sharing Economy*, 66 EMORY L.J. 333, 377 (2017) (noting that the California "rule appears to have served as a model for other states").

89. *See* Miller, *supra* note 70, at 168 (citing the failure of a heavy-handed approach to regulating illegal music sharing).

90. Angela Daly, *Don't Believe the Hype? Recent 3D Printing Developments for Law and Society*, *in* 3D PRINTING AND BEYOND: THE INTELLECTUAL PROPERTY AND LEGAL IMPLICATIONS SURROUNDING 3D PRINTING AND EMERGING TECHNOLOGY (Lemley et al. eds.) (forthcoming 2018) (manuscript at 4), http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2800955 [https://perma.cc/J8BH-BBJA].

91. *See, e.g.*, Eric Biber & J.B. Ruhl, *The Permit Power Revisited: The Theory and Practice of Regulatory Permits in the Administrative State*, 64 DUKE L.J. 133, 219 (2014) (discussing environmental law exemptions for "many of the individually small human actions that contribute to [pressing environmental] harms"); Kevin M. Stack & Michael P. Vandenbergh, *The One Percent Problem*, 111 COLUM. L. REV. 1385, 1394–96 (2011) (identifying various instances in which "[t]he law exempts small contributors and entities from regulation"); Zale, *supra* note 74, at 960–61.

92. Zale, *supra* note 74, at 961–67 (discussing various factors justifying regulatory leniency for small-scale activities).

93. JOHAL & ZON, *supra* note 82, at 14 (noting that sharing economy has transformed the scale of such activities, making them so significant as to require regulatory attention).

environments and existing markets.[94] Under such circumstances, the exemption of small-scale activities may lead to the failure to achieve regulatory goals.[95] Sometimes, regulatory attention to small-scale activity may be warranted even if its expected cumulative effects are small. DIYbio experiments offer an example of seemingly insignificant activity whose potential for catastrophic consequences may necessitate some form of oversight.[96]

B. Barriers to Applying Law

Where existing legal regimes do apply to distributed-innovation activities, logistical, political, and cultural barriers may make it difficult to monitor and enforce existing laws against those activities. Merely identifying participants in distributed-innovation activities poses a challenge because their participation may be sporadic, anonymous, or of low magnitude.[97] Even if participants are identifiable, there are still other logistical challenges, as it can be costly and resource-intensive to administer regulatory requirements to a large number of entities or individuals scattered across various locations. In addition, the application of legal regimes to distributed-innovation activities may also face political difficulties; some individuals resist regulatory burdens they perceive as excessive. Difficulties may be cultural as well. 3D printing, for example, is becoming popular among communities of users that may lack a "history of safe manufacturing, such as maker communities, small startups, schools and hobbyists."[98] Similarly, individual participants in the sharing economy lack the familiarity and expertise of large corporations in navigating complex regulatory requirements.[99]

94. *See, e.g.*, Miller, *supra* note 70, at 160–61 (noting that Airbnb offers more rooms than, and has a market valuation comparable to, the largest hotel chains).

95. *Cf.* Stack & Vandenbergh, *supra* note 91, at 1397–98 (remarking, in context of climate change, that "[s]mall potatoes might be discarded (or discardable), but the calculation for doing so changes if there are only small potatoes").

96. *See supra* notes 25–34 and accompanying text (discussing potential risks associated with DIYbio activities).

97. *See, e.g.*, Holbrook & Osborn, *supra* note 62, at 1323 (observing that digital manufacturing technology "decentralizes and partially anonymizes the manufacture of tangible objects").

98. DAVID REJESKI & YONG HUANG, WILSON CTR., ENVIRONMENTAL AND HEALTH IMPACTS OF ADDITIVE MANUFACTURING 10 (2015), https://www.wilsoncenter.org/sites/default/files/nsf_am_env_final_red.pdf [https://perma.cc/NP2N-8T47].

99. *See* Miller, *supra* note 70, at 167–68 (noting that most participants in short-term rental market "often have no experience with the regulatory structures businesses face in either the physical or administrative environments").

Further complicating matters, the dispersed nature of distributed-innovation activities may make any associated harms difficult to identify. For example, sharing-economy activities may adversely affect neighbors or other members of a community.[100] However, these effects are generally less obvious than those associated with a traditional operator, who, as part of the conventional permitting process, may have adopted measures to mitigate those externalities.[101] Similarly, 3D printing may result in chemical exposure and contribute to chronic health problems.[102] While these sorts of hazards are often overlooked, they may be especially likely to escape attention if they occur in the home. DIYbio also may involve uncertain harms or hazards that are hard to identify. In particular, the risks associated with an engineered microorganism's escape into the environment may be impossible to determine ahead of time.[103] Furthermore, any escape may not be detected until after it is too late to deploy measures to kill or contain the microorganism.

Finally, the dynamic nature of distributed innovation adds a further layer of complexity for would-be regulators. The sharing economy provides perhaps the most obvious example: it has introduced new business models at a dizzying rate, thanks in large part to minimal infrastructure requirements.[104] In these rapidly changing conditions, conventional approaches to regulation, which rely heavily on command-and-control techniques and prescriptive standards, may be unable to respond to change in a timely manner.[105] The rulemaking processes typically used to establish or change such standards are often cumbersome, costly, and time-consuming.[106] A failure to update legal standards can reinforce the status quo or leave innovative technologies without oversight, resulting in regulatory gaps. Regulatory efforts attempting to keep pace with distributed innovation are likely to resemble "a frantic game of 'whack-a-mole'"

100. *See id.* at 170.

101. *See id.* at 170–71 (suggesting that harms associated with short-term residential rentals, though "plausible," ring "as alarmist, the causation highly attenuated," and primarily psychological in nature).

102. *See supra* notes 47–48 and accompanying text.

103. *See* NAT'L ACADS. OF SCIS., ENG'G & MED., PREPARING FOR FUTURE PRODUCTS OF BIOTECHNOLOGY 7, 110–11 (2017) (discussing the development of genomically engineered microorganisms and synthetic communities of microbes that have few or no comparators, as a result of which risk assessment is more difficult).

104. *See* Lobel, *supra* note 65, at 102 ("The most important aspect of the platform economy is that it includes an ecology of continuously evolving business models.").

105. *See* JOHAL & ZON, *supra* note 82, at 14.

106. *See* Albert C. Lin, *Preliminary Injunctive Regulation*, 48 ARIZ. L. REV. 1027, 1035–40 (2016).

as new enterprises rapidly render legal categories and standards obsolete.[107]

None of the above discussion even touches on the jurisdictional issues that distributed innovation raises. Because of their novelty and small scale, distributed-innovation activities often fall into regulatory gaps, thereby raising the issue of who might be an appropriate regulator. Federal, state, or local governments may assume that some other level of government will address a new concern. Within a single level of government, agencies may assume that some other agency will act. And even when an agency recognizes that an issue falls within its jurisdiction, organizational hierarchies and silos may impede the development of an optimal regulatory approach.[108]

Various features of distributed innovation, including difficulty of definition, dynamic change, complexity of causation, fragmented activity, and autonomous social actors, confound conventional regulation.[109] These factors demonstrate that careful attention is needed when designing regulatory tools for these areas and contemplating additional means of oversight. Given these unique features, it may prove especially useful to consider how regulators have addressed regulatory concerns outside of conventional contexts when crafting regulations for distributed innovation.

III. INDIVIDUAL BEHAVIORS & ENVIRONMENTAL LAW

How can society address the challenge of overseeing distributed innovation without unduly hampering it? As this challenge is largely one of managing small-scale behavior, valuable insights may be gained by considering environmental regulatory responses to small-scale behavior in other contexts. First, United States environmental law and legal academics have increasingly directed their attention to individual behaviors that contribute to environmental harms. Second, developing countries have long struggled with addressing small-scale activities that have large cumulative effects on the environment. Experience in these areas suggests that "decentred regulation"—regulation that acknowledges government's limited capacity in certain

107. JOHAL & ZON, *supra* note 82, at 1, 13 (noting that "the speed and scale of change and the difficulty of categorizing [sharing economy] enterprises" are key characteristics that challenge policymakers).

108. *Id.* at 16.

109. *See* Julia Black, *Decentring Regulation: Understanding the Role of Regulation and Self-Regulation in a "Post-Regulatory" World*, 54 CURRENT LEGAL PROBS. 103, 106–12 (2001).

circumstances to control conduct and that enlists nongovernmental actors to assist in the task—offers an important approach.[110]

A. *Recognizing the Role of Individual Behavior in United States Environmental Law*

Historically, American environmental law focused on industrial and commercial facilities (hereafter referred to collectively as "industrial facilities") as the primary subjects of regulation.[111] While current regulation has largely maintained this focus, scholars and regulators have also come to recognize the significant contribution of individual behaviors to environmental problems.

The premise underlying this focus—that industrial facilities generate the bulk of environmental harms and, therefore, should bear the primary burden of addressing them[112]—was generally a reasonable one. Pollution from industrial facilities is often harmful, obvious, and readily controllable. Compared to other pollution sources, such facilities are relatively homogenous, few in number, and, consequently, administratively easier to regulate.[113] Accordingly, the federal and state governments applied schemes of command-and-control regulation to industrial facilities, and, in response to complaints of inefficiency and inflexibility, later added economic incentive programs that continued to focus on these sources.[114] Individuals, by contrast, largely received a "free pass" from federal environmental regulation.[115] The attention to industrial facilities, though somewhat simplistic, yielded substantial progress in reducing pollution.

Significant challenges remain, however, and new threats—most notably climate change—have gained prominence. Perceiving the limitations of focusing on industrial pollution, various scholars have drawn attention to the contributions of individual behavior to climate

110. *See id.* at 112–13.

111. *See* Michael P. Vandenbergh, *From Smokestack to SUV: The Individual as Regulated Entity in the New Era of Environmental Law*, 57 VAND. L. REV. 515, 524–26 (2004).

112. *See* Michael P. Vandenbergh, *The Social Meaning of Environmental Command and Control*, 20 VA. ENVTL. L.J. 191, 206 (2001).

113. *Id.*

114. *See* Vandenbergh, *supra* note 111, at 526–29. In command-and-control schemes, "the government sets both the environmental ends to be achieved . . . and the methods by which they will be achieved . . . ." *Id.* at 526.

115. *See, e.g.*, Katrina Fischer Kuh, *An Unnatural Divide: How Law Obscures Individual Environmental Harms*, *in* ENVIRONMENTAL LAW AND CONTRASTING IDEAS OF NATURE 28, 28–29 (Keith H. Hirokawa ed., 2014).

change, water pollution, and other problems.[116] Environmentally significant individual behaviors include motor vehicle use, household energy consumption, and use of cleaners, pesticides, and other consumer products.[117] These often habitual behaviors may be hard to change, and they frequently take place within the home, making them problematic to police. Yet because of the cumulative environmental significance of these behaviors, regulating industry alone will not be enough.[118] Indeed, individual behavior's proportional contribution to environmental problems will only grow as regulators continue to ratchet down industrial pollution.[119] Failing to regulate individual behavior not only leaves environmental problems unaddressed but also sends a misleading message that individuals are not responsible for environmental harms.[120]

Although the environmental significance of individual behavior has been acknowledged, this recognition has not necessarily prompted its regulation. Indeed, two of the leading federal initiatives to reduce greenhouse gas ("GHG") emissions exemplify a continued focus on industrial sources of pollution. First, the Environmental Protection Agency ("EPA") crafted the 2010 Tailoring Rule, which governs new sources of GHG emissions, specifically to avoid

116. *See* Biber & Ruhl, *supra* note 91, at 214–16; Katrina Fischer Kuh, *When Government Intrudes: Regulating Individual Behaviors That Harm the Environment*, 61 DUKE L.J. 1111, 1114–15 (2012); Michael P. Vandenbergh, *The Individual as Polluter*, 35 ENVTL. L. REP. 10723, 10724 (2005); Vandenbergh, *supra* note 112, at 196; Michael P. Vandenbergh & Anne C. Steinemann, *The Carbon-Neutral Individual*, 82 N.Y.U. L. REV. 1673, 1687–89 (2007).

117. *See* Vandenbergh, *supra* note 111, at 541–84 (examining "individuals' emissions of several important pollutants: low-level ozone or smog, mercury, several air toxics from mobile sources, pesticides, and petroleum"); Vandenbergh & Steinemann, *supra* note 116, at 1690–93 (analyzing "emissions attributable to personal motor vehicle use, personal air travel . . . mass transport. . . . [and] household electricity use").

118. *See* Stack & Vandenbergh, *supra* note 91, at 1388 (describing the "one percent problem" as a situation "where small contributors account for so much of a regulatory problem that the social goal cannot be met without regulating many one percent sources").

119. *See, e.g.*, Vandenbergh, *supra* note 111, at 537–84 (reviewing contributions of individuals to various pollution problems and concluding that "individuals' proportionate share may be growing"); Vandenbergh & Steinemann, *supra* note 116, at 1693–95 (estimating carbon emissions from individual behavior in the United States and their implications).

120. *See* Kuh, *supra* note 115, at 30–31 ("By focusing on commercial and industrial sources of pollution and resource consumption, core environmental statutes might be said to express the view that those commercial and industrial sources are polluters—to be condemned and curbed—while individuals are not."); Vandenbergh, *supra* note 112, at 204–11 (analyzing the potential social perceptions of environmental harm that command-and-control policies created).

regulating smaller sources of GHGs.[121] The EPA feared that literal application of the regulatory thresholds found in the Clean Air Act would require the issuance of 6.1 million permits and $21 billion in administrative costs.[122] Accordingly, the EPA developed higher thresholds designed to require the issuance of only 15,000 permits and impose only $62 million in administrative costs.[123] The centerpiece of the Obama Administration's EPA's GHG reduction efforts, the 2015 Clean Power Plan,[124] provides another example where individual behavior is neglected. This regulation focuses on reducing carbon pollution from power plants rather than on regulating other GHG-generating behavior, including individual behavior, directly.[125]

The pollutant releases and environmental harms caused by individuals do differ in important ways from those caused by industrial facilities.[126] Pollutant releases by individuals come from more numerous sources and are often less than salient.[127] Environmental harms from individual behavior tend to be gradual, cumulative, and less obvious than those caused by industrial sources.[128] Individual pollution is akin to pollution from other dispersed sources such as small businesses, family farms, or nonpoint sources.[129] For dispersed sources of pollution, the large number of sources and their relative lack of familiarity with the regulatory system pose unique challenges for regulation, monitoring, and

121. *See* Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule, 75 Fed. Reg. 31,514, 31,514 (June 3, 2010) (codified in scattered parts of 40 C.F.R.).

122. *See* Util. Air Regulatory Grp. v. EPA, 134 S. Ct. 2427, 2443 (2014). The Supreme Court found the EPA's "rewriting of the statutory thresholds [to be] impermissible" but nevertheless upheld part of the Tailoring Rule under a different statutory provision. *Id.* at 2445, 2448–49.

123. *See id.* at 2443.

124. Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units, 80 Fed. Reg. 64,662, 64,622 (Oct. 23, 2015) (codified at 40 C.F.R. pt. 60).

125. *Id.* The Supreme Court stayed the Clean Power Plan, *see* West Virginia v. EPA, 136 S. Ct. 1000 (2016) (mem.), and the Trump Administration's EPA intends to repeal it. Repeal of Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units, 82 Fed. Reg. 51,787, 51,787 (proposed Nov. 8, 2017); *see also* Lisa Friedman & Brad Plumer, *E.P.A. Announces Repeal of Major Obama-Era Carbon Emissions Rule*, N.Y. TIMES (Oct. 9, 2017), https://www.nytimes.com/2017/10/09/climate/clean-power-plan.html [https://perma.cc/BP8W-TFNS (dark archive)].

126. Vandenbergh, *supra* note 111, at 589.

127. *See id.* at 589–90.

128. *Id.* at 590.

129. *See* Daniel A. Farber, *Controlling Pollution by Individuals and Other Dispersed Sources*, 35 ENVTL. L. REP. 10745, 10746 (2005). The federal Clean Water Act focuses on point sources of pollution and leaves regulation of nonpoint sources largely to the states. *See* HOLLY DOREMUS, ALBERT C. LIN & RONALD H. ROSENBERG, ENVIRONMENTAL POLICY LAW 768–69 (6th ed. 2012).

enforcement.[130] Moreover, whereas we can reasonably predict corporate behavior by assuming that corporations respond rationally to regulation and other incentives,[131] individual behavior is more difficult to predict because of cognitive biases, social influences, and lack of information.[132]

B. *Options for Governing Individual Behavior*

Individual behavior may be more difficult to govern than industrial behavior, but it need not be ungovernable. Options for governing individual behavior include direct regulation, economic incentives, general permits, upstream regulation, social norms, and technological management. This Section describes each of these options and considers their relative merits.

1. Direct Regulation

Conventional wisdom states that traditional methods of regulation are poorly suited for governing environmentally significant individual behavior.[133] Pollution controls typically applied to industrial facilities may not work for small sources, and implementing controls against numerous sources may be too expensive, intrusive, or politically infeasible.[134] Attempts to limit vehicle use in Los Angeles in the 1970s exemplify these difficulties.[135] These efforts, which included gasoline rationing and other seemingly drastic measures, were abandoned after a vehement public reaction.[136] Recent efforts to restrict lawn pesticide use and residential wood burning have sometimes encountered a similar response, resulting in them never going into effect.[137]

130. *See* Farber, *supra* note 129, at 10746.

131. Vandenbergh & Steinemann, *supra* note 116, at 1739.

132. *Id.* at 1739.

133. *See* Kuh, *supra* note 116, at 1120 ("The existing literature's relative inattention to direct mandates on environmentally significant individual behaviors stems from the perception that applying mandates to most environmentally significant individual behaviors would simply be infeasible.").

134. *See* Vandenbergh, *supra* note 111, at 597–98.

135. *See id.* at 555.

136. Craig N. Oren, *How a Mandate Came from Hell: The Making of the Federal Employee Trip Reduction Program*, 28 ENVTL. L. 267, 277–78 (1998). In recent years, congestion pricing has been adopted with some success in London, Singapore, and Stockholm, and it is now under serious consideration in New York City. *See* Christina Anderson et al., *Should New York Look Abroad to Get Out of Its Traffic Jam?*, N.Y. TIMES, Feb. 27, 2018, at A15.

137. Rachel Chason, *Court Strikes Down Montgomery County's Ban on Lawn Pesticides*, WASH. POST (Aug. 3, 2017), https://www.washingtonpost.com/local/md-politics/judge-rules-against-controversial-montgomery-county-ban-on-lawn-pesticides/2017/08/03

Counterexamples nonetheless demonstrate the feasibility of some direct regulation of individuals. State or local laws may prohibit littering or require individuals to conserve water, separate trash, or recycle electronic waste.[138] Local zoning laws restrict what landowners can do on their land.[139] Under certain circumstances federal law also restricts private land use, as through the Endangered Species Act's "take" prohibition and the Clean Water Act's wetlands permitting requirement.[140] Monitoring of individual compliance may involve resource-intensive inspections or high-technology surveillance.[141] To counter objections to direct regulation based on cost, inconvenience, or unfairness, policymakers may offer information, technical help, or other forms of compliance assistance.[142]

Tort law also regulates individual behavior, albeit less directly than command-and-control regulation. While tort law provides an ex post remedy for damages, it also deters ex ante behaviors that could result in liability.[143] Ordinarily, individual conduct is governed by the doctrine of negligence, which imposes a duty to take reasonable precautions against creating risks of injury to others.[144] More demanding standards can apply in special circumstances, however. Strict liability applies to abnormally dangerous conduct or defective products, for example.[145] And the existence of a "special relationship"—for example, as between landlord and tenant, or innkeeper and guest—also can give rise to a heightened duty of care.[146] Regardless of the specific standard that may apply, the general

/7350d7d2-7858-11e7-8f39-eeb7d3a2d304_story.html [https://perma.cc/9NE2-3WC5]; Brian Maffly, *Wood-Burning Ban Coming off the Table*, SALT LAKE TRIB. (Feb. 2, 2015, 9:46 PM), http://archive.sltrib.com/article.php?id=2131384&itype=CMSID [https://perma.cc/6CMY-4S7V].

138. Kuh, *supra* note 116, at 1132–33.

139. *Id.* at 1161.

140. *See id.* at 1135–47 (describing the limits imposed on private behavior by the Clean Air Act, Clean Water Act, and the Endangered Species Act).

141. *See id.* at 1134.

142. *See* Vandenbergh, *supra* note 111, at 599. Many jurisdictions restrict the disposal of used motor oil or require recycling, for example, but they offer convenient drop-off options to reduce incentives for illegal disposal. *See id.*

143. *See* Gary T. Schwartz, *Mixed Theories of Tort Law: Affirming Both Deterrence and Corrective Justice*, 75 TEX. L. REV. 1801, 1816–18, 1831 (1997); *see also* DAN B. DOBBS ET AL., HORNBOOK ON TORTS 23 (2d ed. 2016).

144. *See* RESTATEMENT (THIRD) OF TORTS: PHYSICAL & EMOTIONAL HARM § 6 (Am. Law Inst. 2010); DOBBS ET AL., *supra* note 143, at 197–98.

145. *See* RESTATEMENT (THIRD) OF TORTS: PHYSICAL & EMOTIONAL HARM § 20; RESTATEMENT (THIRD) OF TORTS: PRODUCTS LIABILITY § 1 (Am. Law Inst. 1998); *see also* DOBBS ET AL., *supra* note 143, at 784, 804.

146. *See* Katz, *supra* note 87, at 1077–80 (discussing "assumptions that justify the common law treatment of 'special relationships,' and how these assumptions continue to

applicability of tort law makes it an important backstop to conventional regulation, particularly where new technologies and other changing circumstances can lead to regulatory gaps.[147]

2. Economic Incentives

Government also can encourage environmentally positive behavior or discourage environmentally harmful behavior through subsidies or taxes, which are generally viewed as less coercive than command-and-control regulation.[148] Subsidies and taxes are relatively straightforward to administer. Though subsidies may be more politically palatable than taxes, their financial tab can be a substantial barrier to adoption.[149] Furthermore, subsidies—and taxes—may undermine environmental goals by framing environmental protection as a commodity rather than a moral responsibility.[150]

Economic incentives also include emission allowance trading and similar market-based mechanisms, which have received much attention because of their potential to achieve environmental goals in a cost-effective manner.[151] The utility of such mechanisms for regulating individual behavior may be limited, however. Administrative and transaction costs can be high, particularly when a large number of actors are involved, and these mechanisms require substantial data for successful implementation.[152]

inform modern regulatory frameworks"). *But cf.* DOBBS ET AL., *supra* note 143, at 492 & n.291 (noting several cases where courts did not apply a strict liability standard to landlords).

147. *See* Adam D.K. Abelkop, *Tort Law as an Environmental Policy Instrument*, 92 OR. L. REV. 381, 464–69 (2013); *see also* DOREMUS ET AL., *supra* note 129, at 40.

148. *See* William M. Sage & David A. Hyman, *Combating Antimicrobial Resistance: Regulatory Strategies and Institutional Capacity*, 84 TUL. L. REV. 781, 803–04 (2010). *See generally* Jeroen C.J.M. van den Bergh, *Environmental Regulation of Households: An Empirical Review of Economic and Psychological Factors*, 66 ECOLOGICAL ECON. 559 (2008) (reviewing effect of pricing and other mechanisms on household and individual behavior).

149. Andrew Green, *You Can't Pay Them Enough: Subsidies, Environmental Law, and Social Norms*, 30 HARV. ENVTL. L. REV. 407, 425–26 (2006).

150. *See id.* at 408, 431–33.

151. *See* Daniel P. Selmi, *Federal Implementation Plans and the Path to Clean Power*, 28 GEO. ENVTL. L. REV. 637, 652–53 (2016).

152. *See* Vandenbergh, *supra* note 111, at 601 (noting that "environmental impacts of individual behavior are the product of very small, diffuse releases of pollutants . . . that are widely distributed among victims"). Notwithstanding these limitations, dispersed pollution sources are sometimes incorporated into a pollution trading regime through the use of offsets. *See* Farber, *supra* note 129, at 10752. Under an offset mechanism, regulated entities pay for pollution reductions by unregulated entities and are credited with offsets towards their own pollution emissions. Ensuring that offsets represent real reductions in emissions is often a challenge, however, particularly when the sources generating the

3. General Permits

General permits, which impose relatively light administrative burdens, are one means by which to tailor conventional command-and-control approaches to dispersed pollution sources. Like an ordinary permit, a general permit contains enforceable pollution limits and permit conditions.[153] But unlike an ordinary permit, a general permit applies to multiple sources, which obtain coverage under the permit simply by submitting a notice to the government or otherwise complying with permit conditions.[154] The government may require a source covered by a general permit to apply for an individual permit if the source contributes significantly to pollution, violates the conditions of the general permit, or under other specified circumstances.[155]

General permits have been widely used under the Clean Water Act ("CWA").[156] Section 404 of the CWA, which governs permits for discharging dredged or fill material into the waters of the United States, authorizes the issuance of general permits for activities that "are similar in nature, will cause only minimal adverse environmental effects when performed separately, and will have only minimal cumulative adverse effect on the environment."[157] General permits have also been issued under section 402 of the CWA, which governs discharges of pollution into United States waters.[158] The difficulty of

offsets are dispersed and difficult to monitor. *See* Albert C. Lin, *Myths of Environmental Law*, 2015 UTAH L. REV. 45, 51 (2015).

153. *See* 40 C.F.R. § 122.28 (2017) (providing general permit requirements for various pollutants covered by the National Pollutant Discharge Elimination System); Steven G. Davison, *General Permits Under Section 404 of the Clean Water Act*, 26 PACE ENVTL. L. REV. 35, 67–68 (2009); Jeffrey M. Gaba, *Generally Illegal: NPDES General Permits Under the Clean Water Act*, 31 HARV. ENVTL. L. REV. 409, 410, 419 (2007).

154. *See* Gaba, *supra* note 153, at 410–11, 419 (describing general permits used under Clean Air Act regulatory scheme); *see also* Biber & Ruhl, *supra* note 91, at 156 (distinguishing between an exemption and a general permit in that the latter typically requires the filing of a form). A general permit also differs from an ordinary permit in that a general permit is developed through notice-and-comment rulemaking rather than through individualized adjudication. *See* Biber & Ruhl, *supra* note 91, at 165–66; Gaba, *supra* note 153, at 411.

155. *See, e.g.*, 33 U.S.C. § 1344(e)(2) (2012) (permitting the government to revoke or amend a general permit if "such activities are more appropriately authorized by individual permits"); 40 C.F.R. § 122.28(b)(3) (allowing the EPA to require individual pollution permits under the Clean Water Act regulatory scheme).

156. Clean Water Act, Pub. L. No. 92-500, 86 Stat. 816 (1972) (codified as amended at 33 U.S.C. §§ 1251–1387).

157. 33 U.S.C. § 1344(e) (providing that general permits for dredged or fill material may be revoked or modified if activities have an adverse impact on the environment or are more appropriately authorized by individual permits).

158. *See* 33 U.S.C. § 1342; 40 C.F.R. § 122.28(a).

using individual permits to regulate discharges that are numerous and not readily subject to ordinary pollution control technology, such as storm sewer discharges, prompted the EPA to adopt the general permitting technique.[159]

General permitting systems are less expensive and require less regulatory infrastructure than individual permitting systems.[160] At the same time, general permitting systems can provide information that enables the government to conduct inspections and determine further regulatory needs.[161] Although general permitting systems require agencies to make significant initial investments in a rulemaking process to establish each permit, they do not require as much oversight.[162] Once a general permit issues, the agency need not conduct the assessment, negotiation, and review normally associated with each specific permit.[163] The tradeoff is that general permitting systems do not allow for individualized assessments of harm.[164] Thus, general permits are best suited for classes of activities with relatively predictable and uniform effects, and less so where individualized assessments would provide important information. A higher risk of environmental harm, or high levels of uncertainty regarding the risk of harm, may warrant use of specific permits instead.[165]

One of the most significant reasons to use general permits is political: "General permits can allow for regulation with an especially light touch," and thus may be particularly suited for governing "everyday activities" where there exists "a general expectation that the activity should be permitted."[166] If it turns out that those activities warrant more stringent regulation—perhaps because of increasing levels of activity or new information regarding harmful effects—the existence of a general permit might lay the groundwork for more expansive regulation.[167]

159. *See* Gaba, *supra* note 153, at 420–21, 429–30.

160. *See* Biber & Ruhl, *supra* note 91, at 159, 165–66 (contrasting the process for obtaining a specific permit, which can involve "an enormous and expensive hassle," and obtaining a general permit, which may "ask[] for only a name and an address [and] is a piece of cake").

161. *Id.* at 156.

162. *See id.* at 169.

163. *See id.* at 169, 171.

164. General permitting under the CWA, for example, avoids the usual "site-specific assessment[s] that underlie[] compliance with various elements of water quality standards." Gaba, *supra* note 153, at 433 (discussing how the EPA's NPDES general permit program may violate requirements of the CWA).

165. *See* Biber & Ruhl, *supra* note 91, at 178.

166. *Id.* at 198.

167. *See id.* at 218.

4. Upstream Regulation

Instead of directly regulating individual conduct, a government might influence individual behavior by regulating larger entities that supply the individuals or otherwise relate to individual behavior. By focusing on entities that are logistically easier to regulate, upstream regulation avoids the need to oversee and monitor numerous individual actors' behavior.[168] For example, imposing pollution standards on new car manufacturers is easier than restricting individual drivers or their pollution emissions.[169]

Larger entities may serve as a source of leverage without necessarily restricting individual behavioral options.[170] On their own, or in response to regulatory requirements, energy utilities employ demand response and energy efficiency programs to reduce peak demand or total electricity consumption.[171] Through these programs, utilities offer customers economic incentives to alter how and when they consume electricity.[172] Similarly, extended producer responsibility programs require electronics manufacturers to take back used electronics or to bear the financial responsibility for doing so.[173] These programs incentivize, but do not require, individuals to act in environmentally responsible ways.

Several factors may favor an upstream approach over direct regulation of individuals. When environmental harms are caused by dispersed sources, upstream regulation is generally more feasible and less costly because there are fewer entities to regulate.[174] Upstream regulation can offer greater regulatory coverage to the extent that downstream regulation of some actors is simply not practicable.[175] On

168. *See* Erin T. Mansur, *Upstream Versus Downstream Implementation of Climate Policy*, *in* THE DESIGN AND IMPLEMENTATION OF US CLIMATE POLICY 179, 184–85 (Don Fullerton & Catherine Wolfram eds., 2012); Farber, *supra* note 129, at 10747. Here, downstream regulation refers to the regulation of entities whose conduct is of primary concern, whereas upstream regulation refers to regulation of parties further up the supply or production chain. *See* Mansur, *supra*, at 181.

169. *See* Farber, *supra* note 129, at 10747.

170. *See id.* at 10751–52.

171. *See* Shelley Welton, *Non-Transmission Alternatives*, 39 HARV. ENVTL. L. REV. 457, 465–66 (2015).

172. *See id.*

173. Noah Sachs, *Planning the Funeral at the Birth: Extended Producer Responsibility in the European Union and the United States*, 30 HARV. ENVTL. L. REV. 51, 52–53 (2006).

174. *See* TIM HARGRAVE, CTR. FOR CLEAN AIR POL'Y, US CARBON EMISSIONS TRADING: DESCRIPTION OF AN UPSTREAM APPROACH 6 (1998), http://ccap.org/assets/US-Carbon-Emissions-Trading-Description-of-an-Upstream-Approach_CCAP-March1998.pdf [http://perma.cc/LC5B-F4NZ].

175. *See id.* at 1 (noting that, unlike a downstream system, upstream system for carbon emission trading "would capture virtually all fossil fuel use and carbon emissions").

the flip side, upstream regulation may provide weaker behavioral signals to individual actors than direct regulation downstream.[176] Exclusive reliance on upstream regulation also may result in missed opportunities for additional environmental gains.[177]

5. Activating or Shaping Norms

Individual decisions are motivated not only by economic calculations but also by perceived social sanctions or rewards.[178] Social norms—spoken or unspoken rules that guide social behavior—can powerfully influence individual conduct. Personal norms—"informal obligations that are enforced through an internalized sense of duty to act, as well as guilt or related emotions for a failure to act"—also motivate behavior.[179] The importance of norms to behavior suggests their potential utility in helping to manage the risks of distributed innovation.[180]

Communities can put social pressure on individuals engaging in environmentally harmful behavior to conform to social expectations by drawing attention to such behavior and engaging with the individuals involved.[181] Describing behavioral regularities and disseminating information regarding a behavior's environmental impacts are specific techniques that rely on norms to prompt behavioral change.[182] For example, some hotels encourage towel re-use by describing the commonality of towel re-use or by invoking the environmental benefits of the practice.[183]

176. *See id.* (noting that upstream system for carbon emission trading would offer weaker "incentive[s] for energy efficiency and fuel switching" because of reliance on "price signal[s] rather than direct regulation"); *see also* Mansur, *supra* note 168, at 191 (noting the proposition that "carbon price near the point of emissions . . . will make the policy more salient for the polluter and, therefore, result in greater response").

177. *Compare* HARGRAVE, *supra* note 174, at 2 (noting possibility that "an upstream system [for carbon emission trading] . . . would *provide no incentive to employ end use emissions treatment technologies*"), *with* Mansur, *supra* note 168, at 181 (suggesting use of offsets in upstream regulation schemes to "reward firms for choosing to abate downstream").

178. *See* Michael P. Vandenbergh, Amanda R. Carrico & Lisa Schultz Bressman, *Regulation in the Behavioral Era*, 95 MINN. L. REV. 715, 723 (2011).

179. Vandenbergh & Steinemann, *supra* note 116, at 1706.

180. Tools relying on social norms are often more effective when used in combination with other mechanisms, such as financial incentives and technology mandates. *See* Michael P. Vandenbergh, Jack Barkenbus & Jonathan Gilligan, *Individual Carbon Emissions: The Low-Hanging Fruit*, 55 UCLA L. REV. 1701, 1754 (2008).

181. *See* Farber, *supra* note 129, at 10749–51.

182. *See* Vandenbergh & Steinemann, *supra* note 116, at 1707.

183. *See* Noah J. Goldstein, Robert B. Cialdini & Vladas Griskevicius, *A Room with a Viewpoint: Using Social Norms to Motivate Environmental Conservation in Hotels*, 35 J.

The premise underlying these approaches is that recipients of information will individually determine that their behavior is inappropriate and then change their behavior accordingly.[184] Because individuals often behave in accordance with *perceived* norms, presenting information regarding descriptive norms may correct misperceptions about actual behavior.[185] Describing a behavior as common may not always lead to the desired behavioral change, though; increasing the awareness of descriptive norms could *encourage* those individuals who do not usually engage in undesirable but common behavior to start behaving this way more often.[186] Focusing on the harmful effects of individual behaviors, or on social disapproval of such behaviors, may help to activate norms regarding appropriate conduct.[187]

Lack of information may be only one of several barriers to behavioral change.[188] If individuals perceive behavioral change as inconvenient or ineffective, additional tools may be needed to counter that perception.[189] Of particular interest are tools that build on behavioral scientists' insights regarding cognitive biases and the

CONSUMER RES. 472, 473–75 (2008) (finding the use of descriptive norms to be more effective than the invocation of environmental benefits in bringing about towel re-use).

184. *See* Vandenbergh & Steinemann, *supra* note 116, at 1705. For example, an "Individual Carbon-Release Inventory" might disclose data on carbon emissions from individuals and suggest behavioral changes with the goal of reducing carbon emissions. *Id.* at 1729–32.

185. *See* Kevin Burchell, Ruth Rettie & Kavita Patel, *Marketing Social Norms: Social Marketing and the 'Social Norm Approach',* 12 J. CONSUMER BEHAV. 1, 5–6 (2013) (using descriptive norms "exploit[s] the fact that people tend to conform [their behavior] to what they understand to be the norm"); Vandenbergh et al., *supra* note 178, at 752–54 (offering examples of groups effectively using descriptive norms to change individuals' behavior).

186. *See* P. Wesley Schultz et al., *The Constructive, Destructive, and Reconstructive Power of Social Norms*, 18 PSYCHOL. SCI. 429, 430 (2007).

187. *See* Vandenbergh & Steinemann, *supra* note 116, at 1709, 1729–31; *see also* Schultz et al., *supra* note 186, at 430, 432–33 (finding that combining descriptive information with an injunctive message reduced the tendency of descriptive norms to inadvertently increase levels of undesirable behavior among those who already abstain from such behavior).

188. *See* Philip K. Lehman & E. Scott Geller, *Behavior Analysis and Environmental Protection: Accomplishments and Potential for More*, 13 BEHAV. & SOC. ISSUES 13, 18 (2004) ("[I]nformation alone is seldom sufficient to change behavior."); Doug McKenzie-Mohr, *Promoting Sustainable Behavior: An Introduction to Community-Based Social Marketing*, 56 J. SOC. ISSUES 543, 547 (2000) (noting importance of identifying barriers to a desired behavior and explaining that these "barriers . . . may be internal . . . or external").

189. *See* Vandenbergh et al., *supra* note 178, at 754–55; *see also* DOUG MCKENZIE-MOHR, FOSTERING SUSTAINABLE BEHAVIOR: AN INTRODUCTION TO COMMUNITY-BASED SOCIAL MARKETING 41–127 (3d ed. 2011) (offering various strategies to enhance social marketing).

limitations of rational choice theory in predicting behavior.[190] These tools include incentives, behavioral nudges—which seek to change people's behavior "without forbidding any options or significantly changing their economic incentives"[191]—and other measures that lower the economic, social, or psychological costs of behavioral change.[192] Asking individuals to make a commitment based on their beliefs, and subsequently reminding them of that commitment, can change behavior, particularly if the commitment is public and in writing.[193] Similarly, frequent feedback can be an effective tool for influencing ongoing behavior.[194] Such feedback might encourage individuals to engage in environmentally positive behaviors by quantifying such behaviors or describing their effect on the environment.[195]

6. Technological Management

Technological management offers yet another approach to governing individual behavior. Technological management refers to "the design of products or places, or the automation of processes . . . seek[ing] to exclude . . . the possibility of certain actions."[196] Strictly speaking, technological management is not a legal tool. However, technological management functions like law by steering conduct in a desired direction or making certain conduct practically or physically impossible. Technological management of individual behavior typically occurs at the design or engineering stage. For example,

190. *See* Vandenbergh et al., *supra* note 178, at 716–17; *see also* Jeffrey J. Rachlinski, *The Psychological Foundations of Behavioral Law and Economics*, 2011 U. ILL. L. REV. 1675, 1675 (noting that behavioral law and economics recognizes "that human behavior commonly deviates from predictions of rational choice theory").

191. RICHARD H. THALER & CASS R. SUNSTEIN, NUDGE: IMPROVING DECISIONS ABOUT HEALTH, WEALTH, AND HAPPINESS 6 (2008); *see also* Pierre Schlag, *Nudge, Choice Architecture, and Libertarian Paternalism*, 108 MICH. L. REV. 913, 915–16 (2010) (discussing default rules, "priming," and other examples of behavioral nudges).

192. *See* THALER & SUNSTEIN, *supra* note 191, at 6–8; *see also* McKenzie-Mohr, *supra* note 188, at 548 (listing a variety of tools policymakers can use to create effective social marketing campaigns).

193. *See* MCKENZIE-MOHR, *supra* note 189, at 45–56; Lehman & Geller, *supra* note 188, at 20; Vandenbergh et al., *supra* note 178, at 759. Commitment strategies can require significant investments of resources to engage individuals, however. *See* MCKENZIE-MOHR, *supra* note 189, at 54; McKenzie-Mohr, *supra* note 188, at 546–57. A less labor-intensive strategy is to prompt individuals with oral or written messages stating desired behaviors. Lehman & Geller, *supra* note 188, at 19; *see also* MCKENZIE-MOHR, *supra* note 189, at 83–87 (discussing the mechanics and examples of effective prompting).

194. Lehman & Geller, *supra* note 188, at 21–22; van den Bergh, *supra* note 148, at 568.

195. *See* Lehman & Geller, *supra* note 188, at 21–22.

196. Roger Brownsword, *In the Year 2061: From Law to Technological Management*, 7 L. INNOVATION & TECH. 1, 8 (2015).

traffic engineers may narrow roads to reduce vehicle speeds and traffic volume,[197] and manufacturers may include automatic shut-off features in appliances to reduce energy use.[198] Software code serves as a form of technological management as well, regulating communications and interactions in cyberspace.[199] In other cases, technological management may substitute directly for law, as illustrated by the potential for self-driving cars to make many highway safety laws superfluous.[200] As the "Internet of Things"—the networking of physical devices to send and receive data—expands,[201] technological management will play an increasingly prominent role in governing individual behavior.[202]

Technological management does not involve the same level of coercion as direct prohibition. Whereas a prohibition identifies what is not allowed and to whom the prohibition applies, technological management is more subtle. Such an approach may obscure the existence of regulation and its extent, and perhaps the identity of the regulator as well.[203] These features may make technological management more politically feasible than direct regulation but also may raise concerns regarding political accountability and individual autonomy.[204]

C. Governance of Small-Scale Activities in Developing Countries

The challenge of regulating individual behavior is not confined to developed countries. In developing countries, small-scale actors are responsible for an especially large share of environmental harms. The challenge of regulating these small-scale activities is analogous to that posed by distributed innovation: numerous and widespread regulatory targets, limited government capacity to regulate directly, lack of awareness regarding environmental problems, and political

197. Reid Ewing & Eric Dumbaugh, *The Built Environment and Traffic Safety: A Review of Empirical Evidence*, 23 J. PLAN. LITERATURE 347, 355–56, 363 (2009).

198. Brownsword, *supra* note 196, at 24–25 (detailing potential product features that could control energy use and vehicle speed).

199. *See* LAWRENCE LESSIG, CODE: VERSION 2.0 56–57, 72 (2006) (explaining the means by which software development and code can be used to regulate network users).

200. Brownsword, *supra* note 196, at 48.

201. *See* JAMES MANYIKA ET AL., MCKINSEY GLOB. INST., DISRUPTIVE TECHNOLOGIES 4–6 (2013), https://www.sommetinter.coop/sites/default/files/etude/files/report_mckinsey_technology_0.pdf [https://perma.cc/28UK-Y393].

202. *See* Brownsword, *supra* note 196, at 7 ("[T]echnological management promises to be the strategy of choice for public regulators of the present century." (footnote omitted)).

203. *See id.* at 16; *see also* LESSIG, *supra* note 199, at 138 ("Code-based regulation . . . risks making regulation invisible.").

204. *See* Brownsword, *supra* note 196, at 9–10.

resistance.[205] To be sure, small-scale activities in developing countries have distinctive features—environmentally sloppy practices may be driven by poverty, and regulatory institutions may be especially weak or poorly supported[206]—but experience in managing these activities may nevertheless be instructive in managing distributed innovation.

Addressing environmental problems caused by small-scale industrial activity in developing countries often involves the promotion of "cleaner production"—instilling less wasteful and more energy-efficient production processes that offer economic benefits for the target actor as well as safety and environmental benefits.[207] Barriers to adopting cleaner production methods may be attitudinal, organizational, technical, and economic.[208]

One example of a small-scale activity with significant health and environmental impacts is the small-scale mining activity conducted by millions of people in developing countries. Small-scale mining operations often take place with minimal environmental safeguards because of financial limitations and a lack of information and oversight.[209] Miners are often subject to toxic chemicals and dangerous work environments, and their operations contribute to mercury contamination, erosion, deforestation, and other forms of environmental degradation.[210] Strategies for preventing and addressing such impacts include: adopting a licensing system tailored to small-scale operations; offering training and other educational initiatives; establishing formal organizations or regional centers to provide support and training; developing partnerships with large mining organizations to disseminate best practices; registering small-scale operators with large-scale companies on whose properties they operate; and providing better ore-processing equipment.[211]

205. *See* Philip Andrews-Speed et al., *The Regulation of China's Township and Village Coal Mines: A Study of Complexity and Ineffectiveness*, 11 J. CLEANER PRODUCTION 185, 185 (2003); Jos Frijns & Bas van Vliet, *Small-Scale Industry and Cleaner Production Strategies*, 27 WORLD DEV. 967, 971 (1999).

206. *See, e.g.*, Oliver Maponga & Clay F. Ngorima, *Overcoming Environmental Problems in the Gold Panning Sector Through Legislation and Education: the Zimbabwean Experience*, 11 J. CLEANER PRODUCTION 147, 155 (2003).

207. *See* Frijns & van Vliet, *supra* note 205, at 975.

208. *See id.* at 977–78.

209. *See* Benjamin N.A. Aryee, Bernard K. Ntibery & Evans Atorkui, *Trends in the Small-Scale Mining of Precious Minerals in Ghana: A Perspective on Its Environmental Impact*, 11 J. CLEANER PRODUCTION 131, 136 (2003).

210. *See* Gavin Hilson, *Small-Scale Mining and Its Socio-Economic Impact in Developing Countries*, 26 NAT. RESOURCES F. 3, 8–9 (2002).

211. *See* Aryee et al., *supra* note 209, at 137–39; Hilson, *supra* note 210, at 9–11; Wilfred C. Lombe, Editorial, *Small Scale Mining and the Environment: Bloom Beyond the Doom and Gloom?*, 11 J. CLEANER PRODUCTION 95, 96 (2003). Furthermore, the

What these strategies have in common is a "soft law" touch—they shy away from complex regulation, strive to educate rather than coerce, and devolve power away from central government to local or private entities. A similar approach might also be effective in distributed-innovation contexts involving numerous actors who have limited information and resources.

IV. GOVERNING DISTRIBUTED INNOVATION

Having reviewed various approaches for governing individual or small-scale behavior, we return to the challenge of governing distributed innovation. While some of the approaches for governing small-scale behavior offer useful suggestions, distributed innovation poses distinct difficulties for oversight. This Part discusses these difficulties and suggests three categories of options for distributed-innovation governance: (1) a "Big Data/Big Government" approach; (2) an approach that relies on nongovernmental intermediaries for oversight; and (3) a self-regulatory approach.

A. The Further Complexity of Governing Distributed Innovation

The regulatory challenge presented by distributed innovation has much in common with the challenge posed by pollution from small-scale sources. Both grapple with the difficulty of governing the conduct of parties that are numerous, unaccustomed to regulation, and largely outside the regulatory system.

As compared with other forms of small-scale activity, distributed innovation possesses several characteristics that make governance especially complex. First, the effects of distributed innovation may be particularly uncertain because the activities at issue are new and constantly changing. A new activity may be easier to shape. The uncertainty of a new activity's effects, however, may make it impossible for a government to determine if regulation is necessary in the first instance. Further, if a government does decide to regulate, some tools, such as information dissemination or specific permits, may be difficult to deploy effectively in the absence of accurate information. Second, distributed innovation confronts would-be regulators with moving targets. The innovation process is inherently dynamic. Consequently, setting up a permit system or other regulatory scheme predicated on current types, levels, and impacts of

establishment of secure property rights to mineral land can provide an incentive to invest in knowledge and physical capital. *See* Knud Sinding, *The Dynamics of Artisanal and Small-Scale Mining Reform*, 29 NAT. RESOURCES F. 243, 244, 247, 251 (2005).

activity may not work. Third, the potential for catastrophic harms—as in the case of DIYbio[212]—suggests a small margin for regulatory error. For ordinary small-scale behaviors with cumulatively significant impacts, less-than-complete regulatory coverage and compliance may not prevent achievement of regulatory goals. In contrast, the failure to regulate a particular distributed innovator—for example, a DIY biologist engaging in the release of experimental organisms—may matter in ways that the failure to regulate a small-scale polluter may not.

The distinctive characteristics of distributed innovation make it difficult to directly transplant techniques used to govern small-scale behavior in other contexts. Such techniques may be useful starting points for managing the risks of distributed innovation, but policymakers should conduct a context-specific analysis before choosing a particular course. Indeed, the distinctive features of distributed innovation—change, novelty, and potential for catastrophe—are among the qualities that have prompted scholars to turn from conventional regulation to the broader and more flexible notion of governance.[213] Governance—the making and implementation of norms by public actors as well as businesses, nonprofit organizations, and other private actors[214]—offers a more sophisticated approach for responding to economic and social conditions that are often too complex, uncertain, volatile, and heterogeneous to be managed through conventional regulatory approaches.[215] Examples of governance by private actors include accreditation and certification schemes, third-party monitoring and verification, and voluntary codes of conduct.[216] Governance by private actors can bring additional societal resources to address problems and attract the support of key stakeholders.[217] Private involvement, however, can also raise concerns regarding accountability and legitimacy.[218]

212. *See supra* notes 25–34 and accompanying text.

213. *See* Orly Lobel, *The Renew Deal: The Fall of Regulation and the Rise of Governance in Contemporary Legal Thought*, 89 MINN. L. REV. 342, 357–58 (2004).

214. *See id.* at 344; *see also* Bradley C. Karkkainen, *"New Governance" in Legal Thought and in the World: Some Splitting as Antidote to Overzealous Lumping*, 89 MINN. L. REV. 471, 474 (2004).

215. *See* Lobel, *supra* note 213, at 357–58.

216. *See id.* at 374–75; Lesley K. McAllister, *Regulation by Third-Party Verification*, 53 B.C. L. REV. 1, 2–4 (2012).

217. *See* Lester M. Salamon, *The Tools Approach and the New Governance: Conclusion and Implications*, *in* THE TOOLS OF GOVERNMENT: A GUIDE TO THE NEW GOVERNANCE 600, 602–03 (Lester M. Salamon ed., 2002).

218. *See id.* at 602–05.

The concept of governance is consistent with Larry Lessig's identification of law as just one of four possible "modalities of regulation."[219] Other modalities of regulation, according to Lessig, include: social norms, which communities, rather than governments, enforce; markets, which "regulate by price"; and architecture, which regulates by physically or virtually constraining an activity.[220] These different modalities may operate simultaneously in an environment, interacting with and influencing each other.[221]

In choosing from among these modalities or from among governance options, policymakers might consider criteria such as effectiveness, efficiency, equity, manageability, adaptability, political feasibility, and legitimacy.[222] The objective here, however, is not to assess the ultimate desirability of any specific policy instrument according to these criteria. Rather, the criteria are presented as a starting point for government or nongovernmental entities as they consider options for addressing the risks of distributed innovation.[223] The importance of each factor will depend on context and on the priorities of decision makers and stakeholders.[224] Effectiveness may be critical when a program is designed to address very serious or

219. Lawrence Lessig, *The Law of the Horse: What Cyberlaw Might Teach*, 113 HARV. L. REV. 501, 507 (1999).

220. *Id.* at 507–08. Architecture includes the earlier discussed tool of technological management, which "responds to a perceived risk by either removing humans from the activity in question or by designing products, places, and even people in ways that exclude the risky act." Brownsword, *supra* note 196, at 10.

221. *See* Lessig, *supra* note 219, at 511–12.

222. *See* Peter Bohm & Clifford S. Russell, *Comparative Analysis of Alternative Policy Instruments*, *in* 1 HANDBOOK OF NATURAL RESOURCE & ENERGY ECONOMICS 395, 399–401 (Allen V. Kneese & James L. Sweeney eds., 1985) (identifying "[d]imensions for judging environmental policy instruments"); Lester M. Salamon, *The New Governance and the Tools of Public Action: An Introduction*, 28 FORDHAM URB. L.J. 1611, 1647–50 (2001) (discussing criteria for assessing policy interventions); *see also* Robert W. Hahn & Robert N. Stavins, *Economic Incentives for Environmental Protection: Integrating Theory and Practice*, 82 AM. ECON. REV. 464, 464 (1992) (discussing potential criteria for analyzing policy).

223. As Sarah Light and Eric Orts have suggested in the context of global environmental governance, "there is no omniscient single 'chooser' of options"; rather, "there are many 'choosers': governments (at multiple levels), private business firms, NGOs, and individuals acting as both consumers and citizens." Sarah E. Light & Eric W. Orts, *Parallels in Public and Private Environmental Governance*, 5 MICH. J. ENVTL. & ADMIN. L. 1, 10–11 (2015).

224. *See* Robert M. Friedman, Donna Downing & Elizabeth M. Gunn, *Environmental Policy Instrument Choice: The Challenge of Competing Goals*, 10 DUKE ENVTL. L. & POL'Y F. 327, 327–28 (2000); *see also* Light & Orts, *supra* note 223, at 11 ("The appropriate governance solution for a particular problem will depend upon the specific context of a problem, available alternative tools, and a weighing of different normative considerations.").

catastrophic risks,[225] for example, whereas adaptability may receive special consideration when governance is at an early stage.

B. Three Basic Approaches

As the earlier discussion suggests, the policy literature offers a range of tools that could assist in the oversight of distributed innovation. Ultimately, these tools fall into three categories: (1) a "Big Data/Big Government" approach that takes advantage of Big Data advances to apply existing law or develop new regulatory programs; (2) an approach that relies heavily on nongovernmental intermediaries to serve as the frontline or primary means of oversight; and (3) a self-regulatory approach in which persons engaged in distributed innovation take on substantial responsibility for overseeing themselves.

This typology and Lessig's categorization of regulatory modalities[226] do overlap in some ways: just as norms, markets, and architecture offer alternative modalities of regulation, nongovernmental intermediaries and private actors can substitute for government regulators. Lessig's approach, however, is especially concerned with the means of regulation and focuses on architecture as an often-overlooked method.[227] In contrast, the typology presented here zeroes in on the actor responsible for a constraint rather than the nature of the constraint. A primary focus on *who* does the governing, with a secondary focus on *how* the governing should be done, is appropriate because it prompts an inquiry into whether the entity is capable, accountable, and democratically responsible. Distributed innovation calls into question government's ability to respond, and thus the question of "Who else might govern?" is a critical one. The challenge involves a matter of not only picking a different tool from the regulatory toolbox but also re-conceptualizing oversight and identifying alternative agents of governance.

1. Big Data/Big Government

The "Big Data/Big Government" response to distributed innovation would capitalize on the huge quantities of data being

225. *See* Friedman et al., *supra* note 224, at 345.

226. *See supra* notes 219–21 and accompanying text.

227. *See* Viktor Mayer-Schönberger, *Demystifying Lessig*, 2008 WISC. L. REV. 713, 716–17. For further discussion of what Lessig means by "architecture," see *supra* note 220 and accompanying text.

produced and the growing capacity to collect and process it.[228] In some areas, the same technologies that make distributed innovation possible also would facilitate government tracking and anticipation of distributed-innovation activities. For example, the digital advances that make the sharing economy possible also allow activities within that economy to be monitored, analyzed, and overseen. Where data collection is routine, one can readily imagine a regulatory scheme relying on that data. Government might then adapt existing regulations to account for the unique aspects of the new, innovative activity.[229]

The specific steps government might take under a Big Data/Big Government approach will depend on a community's values and the weighing of relevant tradeoffs.[230] One relatively light-handed option would be to require general permits of small-scale operators rather than more onerous individual permits.[231] Such an approach could hold operators to minimal standards while providing data to help regulators decide if more oversight is needed. Another option would be to use performance-based regulations, which would set regulatory standards but allow regulated entities flexibility in how they achieve specified results.[232] Government could also undertake more comprehensive reform: rather than merely modifying existing schemes to account for distributed innovation's unique features,

228. I use the term "Big Data" to refer generally to the collection, analysis, and use of large data sets as the basis for corporate or governmental decision-making. Various definitions of the term focus on the use of supercomputers to find patterns and generate predictions based on data or on the "high-volume, high-velocity, and high-variety" features of data. *See, e.g.*, Margaret Hu, *Small Data Surveillance v. Big Data Cybersurveillance*, 42 PEPP. L. REV. 773, 794–97 (2015).

229. *See* Lobel, *supra* note 65, at 129–30 (noting the need for data analysis when governments craft regulations for Airbnb); *see also* JANELLE ORSI ET AL., SHAREABLE & SUSTAINABLE ECONOMIES L. CTR., POLICIES FOR SHAREABLE CITIES: A SHARING ECONOMY POLICY PRIMER FOR URBAN LEADERS 15–16, 18–19, 21 (2013), https://www.shareable.net/blog/new-report-policies-for-shareable-cities [https://perma.cc/6SHA-4NQY] (providing examples of local governments adapting existing policies or adopting new policies to incentivize innovations in urban farming and cottage food industries).

230. *See* Lobel, *supra* note 65, at 129–30.

231. *See supra* Section III.B.3; *see also* Biber & Ruhl, *supra* note 91, at 232–33 (suggesting the use of general permits for regulating sharing economy activity); Eric Biber & J.B. Ruhl, *Regulating the "Sharing Economy*,*"* REGULATORY REV. (July 28, 2014), http://www.regblog.org/2014/07/28/28-biber-ruhl-regulating-the-sharing-economy/ [https://perma.cc/QZ62-Y9KT].

232. *See* JOHAL & ZON, *supra* note 82, at 24 (arguing that performance-based regulations would more effectively regulate the sharing economy than command-and-control policies).

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government might view distributed-innovation activity as an opportunity to modernize overall regulatory policies.[233]

Adoption of a Big Data/Big Government regulatory approach may require government intrusion into activity that in some instances is considered personal or proprietary. Consequently, Big Data/Big Government approaches raise concerns regarding transparency, autonomy, and protection of privacy.[234] Big Data collects data through opaque techniques, and the institutions that use the data hold tremendous power.[235] Furthermore, technology concealing users' identities may in some instances confound Big Data/Big Government approaches.[236]

Notwithstanding such concerns, government likely will play a significant role in distributed-innovation oversight. Distributed innovation and any attendant harms will be the subject of intense public concern. Government possesses substantial resources to make and enforce the law, and it is authorized generally to represent the public. In at least some contexts, government will be the most effective protector of the public and public values, even if it cannot use conventional regulatory methods.[237]

2. Nongovernmental Intermediaries

Governance includes a range of "actions taken by non-governmental entities that are designed to achieve traditionally governmental ends."[238] These actions may be legally mandated or purely voluntary. Private environmental governance includes self-regulation, discussed in the next Section, and governance by nongovernmental intermediaries. Nongovernmental intermediaries often have information, skills, or resources the government lacks and may be able to act where jurisdictional gaps or other constraints

233. *See* Zon, *supra* note 65, at 5–6 ("[G]overnments should take a step back and use this transition as an opportunity to revisit what their primary policy objectives are and whether existing policies are meeting those goals.").

234. *See* Neil M. Richards & Jonathan H. King, *Three Paradoxes of Big Data*, 66 STAN. L. REV. ONLINE 41, 42–45 (2013).

235. *See id.*

236. *See* Snow, *supra* note 1, at 82 ("[I]ntelligence signatures will be reduced by the use of anonymizing tools and dark networks.").

237. *See* Bryant Cannon & Hanna Chung, *A Framework for Designing Co-Regulation Models Well-Adapted to Technology-Facilitated Sharing Economies*, 31 SANTA CLARA HIGH TECH. L.J. 23, 57–58 (2015) ("Firms left unchecked, so the argument goes, will put their own profits ahead of the public interest, and self-regulatory standards will inevitably prove too lenient.").

238. Michael P. Vandenbergh, *Private Environmental Governance*, 99 CORNELL L. REV. 129, 146 (2013).

prevent government action.[239] Unhindered by processes applicable to government decision-making, these entities may be able to develop and adapt programs rapidly in response to changing circumstances or local conditions.[240]

Examples of private environmental governance by nongovernmental intermediaries include eco-labeling and certification systems, lending standards, environmental management standards, and supply chain contracts.[241] Many of these examples involve large corporations, which can serve as a fulcrum of leverage over those who depend on them, such as small suppliers.[242] But private governance efforts are not limited to large corporations. Insurers, banks, certification organizations, industry associations, and nonprofits are just some of the entities that exercise regulatory authority over private activity.[243] Such entities may monitor and challenge industry behavior, gather and disseminate information, or cooperate with industry to establish and implement standards of conduct.[244]

Of course, the goals and agendas of nongovernmental entities may not coincide with the public interest.[245] Private entities may adopt governance measures in an effort to ward off more restrictive public regulation.[246] Nongovernmental intermediaries may be interested primarily in cultivating more business or burnishing their reputations. Furthermore, various constitutional and statutory obligations designed to foster openness, accountability, fairness, and public participation do not apply to nongovernmental actors.[247] To counter such concerns, nongovernmental entities may disclose information voluntarily or adopt other quasi-public measures. Active government

239. *See id.* at 161; *see also* Paul L. Posner, Accountability Challenges of Third-Party Governance 2 (June 2004) (unpublished paper prepared for the 20th Anniversary Structure and Organization of Government Research Committee of the International Political Science Association), http://faculty.arts.ubc.ca/campbell/sog-conf/papers/sog2004-posner.pdf [https://perma.cc/U4SW-UHV2].

240. *See* Posner, *supra* note 239, at 2.

241. *See* Vandenbergh, *supra* note 238, at 148–61.

242. *See id.* at 168–69.

243. *See* Salamon, *supra* note 222, at 1613–14.

244. *See* Yishai Blank & Issi Rosen-Zvi, *The Persistence of the Public/Private Divide in Environmental Regulation*, 15 THEORETICAL INQUIRIES L. 199, 218–19 (2014).

245. *See* Posner, *supra* note 239, at 15.

246. *See* Vandenbergh, *supra* note 238, at 186–87.

247. *See* Jody Freeman, *Extending Public Law Norms Through Privatization*, 116 HARV. L. REV. 1285, 1301–02 (2003) (noting a group's concern "about privatization's implications for what they regard as liberal democratic norms of accountability, due process, equality, rationality, and the like"); Posner, *supra* note 239, at 7 ("Third party providers have independent bases of political power . . . .").

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oversight of nongovernmental intermediaries also can provide a measure of accountability and bring pressure to align intermediaries' interests with those of the general public.[248]

Reliance on nongovernmental intermediaries may be combined with government regulation. Take, for example, upstream regulation, in which government directly regulates larger entities that in turn influence behavior by smaller entities or individuals.[249] Upstream regulation makes particular sense in the case of repeat players, who not only have greater regulatory sophistication but also face stronger incentives to correct externalities and comply with regulatory requirements.[250] Unsurprisingly, regulatory efforts in the distributed innovation context have focused on Uber, Airbnb, and 3D-printer manufacturers rather than on occasional Uber drivers, Airbnb hosts, or 3D-printer users.[251] These repeat players generally are easier to track and can adopt precautions against risk at the lowest cost.[252]

3. Self-Regulation

Government may rely on industry members to regulate themselves when it lacks sufficient information, political will, or resources to regulate effectively.[253] Compared with government, the industry or community to be regulated often has superior information regarding risks and risk-reduction strategies.[254] Industry can often monitor and control its own operations more effectively than

248. *See* McAllister, *supra* note 216, at 32–33.

249. *See supra* Section III.B.4.

250. *See* Cannon & Chung, *supra* note 237, at 35 (discussing "incentives gap" between inexperienced sharing economy actors with little incentive "to self-impose an optimal level of forethought and safeguards" and platform developers and government regulators with long-term incentives to correct market inefficiencies).

251. *See* Rauch & Schleicher, *supra* note 73, at 922–24 (discussing local government efforts to regulate "non-professional" services by regulating the sharing economy platforms).

252. *See* Katz, *supra* note 87, at 1101–03 (explaining why sharing platforms, not service providers, are "either the least-cost avoider or the easiest target for enforcement agencies").

253. *See* Jodi L. Short, *Self-Regulation in the Regulatory Void: "Blue Moon" or "Bad Moon"?*, 649 ANNALS AM. ACAD. POL. & SOC. SCI. 22, 27–28 (2013) (identifying knowledge voids, political voids, and institutional voids as the three types of "regulatory voids" self-regulation typically is meant to address).

254. *See* Cannon & Chung, *supra* note 237, at 32; Douglas C. Michael, *Federal Agency Use of Audited Self-Regulation as a Regulatory Technique*, 47 ADMIN. L. REV. 171, 181 (1995).

outsiders.[255] And in rapidly changing environments, industry can often better anticipate developments and more readily adjust standards.[256]

As with governance through nongovernmental intermediaries, self-regulation need not be exclusive of other forms of governance. Self-regulation may be voluntary, formulated in response to the threat of government regulation, or sanctioned by the government.[257] Government might even mandate self-regulation by setting overarching goals and then allowing industry to determine and implement standards to achieve those goals.[258] Often, self-regulation is part of a complex regulatory environment in which public and private actors cooperate in creating and implementing rules.[259]

Understandably, self-regulation carries some negative connotations. The metaphor of the fox guarding the hen house reflects the serious concerns regarding self-interested behavior, lack of transparency, and dubious accountability.[260] Self-regulation, however, typically involves more than a company policing itself. The term often refers to a group of industry peers or a professional association regulating behavior.[261] Indeed, effective self-regulation may require a network of relationships within an industry.[262] Even then, additional safeguards may be necessary for self-regulation to be fair and effective. Participation by independent third parties, public scrutiny, professional norms, and the threat of government regulation

255. Saule T. Omarova, *Rethinking the Future of Self-Regulation in the Financial Industry*, 35 BROOK. J. INT'L L. 665, 670 (2010).

256. Cannon & Chung, *supra* note 237, at 32; *see also* Michael, *supra* note 254, at 182, 243 (concluding from a survey that audited self-regulation offers advantages of flexibility and superior technical expertise).

257. Black, *supra* note 109, at 118; *see also* Michael, *supra* note 254, at 175–77 (distinguishing between voluntary private standard setting and delegation of government power to nongovernmental entity to implement laws or regulations).

258. *See* Cannon & Chung, *supra* note 237, at 55; *see also* Jody Freeman, *The Private Role in Public Governance*, 75 N.Y.U. L. REV. 543, 551–52, 644–45 (2000) (describing "[t]he [p]ervasive [p]rivate [r]ole" in crafting and enforcing regulations and how to structure "[a]n effective self-regulatory system").

259. *See* Omarova, *supra* note 255, at 675–76 (discussing concept of "co-regulation").

260. *See* Black, *supra* note 109, at 115 (noting a perception that self-regulation "is self-serving, self-interested, lacking in sanctions, beset with free rider problems, and simply a sham"); Freeman, *supra* note 258, at 647 ("[S]elf-regulation raises accountability concerns.").

261. *See* Molly Cohen & Arun Sundararajan, *Self-Regulation and Innovation in the Peer-to-Peer Sharing Economy*, 82 U. CHI. L. REV. DIALOGUE 116, 123–25 (2015) (discussing types and examples of "self-regulatory organizations").

262. *See* Freeman, *supra* note 258, at 644.

all can motivate compliance with self-regulatory approaches and lessen accountability concerns.[263]

Oversight of distributed innovation is characterized precisely by the informational challenges, implementation difficulties, and changing conditions that make self-regulation an attractive alternative to conventional governmental regulation. In all likelihood, the very communities that participate in distributed innovation will be central to managing distributed innovation's risks. These groups obviously influence how a technology develops and what risks arise as they share information and disseminate a technology.[264] But these communities will also have a more direct role in risk management. To some extent, these groups police themselves and punish violators of community norms through a range of techniques, including reputational sanctions, cyber vigilantism, and denial of access to community goods.[265] These communities can share expert knowledge with the government and provide insight into the effectiveness of potential oversight mechanisms.[266] Furthermore, distributed-innovation communities can be especially valuable contributors to risk management efforts because they often are not bound by the physical, legal, temporal, and geographic constraints that apply to conventional government oversight.[267]

V. GOVERNANCE OPTIONS FOR DISTRIBUTED INNOVATION

This Part considers how various governance options are beginning to appear—or might be further applied—in the specific contexts of DIYbio, 3D printing, and the sharing economy. Given distributed innovation's varied forms and the challenges it poses for conventional regulation, the variety of governance approaches is unsurprising. There is no one-size-fits-all solution to the challenges posed by distributed innovation. Going forward, those engaged in governance efforts will wrestle with competing objectives of encouraging innovation, protecting people and the environment, and safeguarding privacy and democratic values.

263. *See id.* at 665–66; Michael, *supra* note 254, at 192–93; Short, *supra* note 253, at 24–26.

264. *See* Snow, *supra* note 1, at 19.

265. *See id.* at 48 (discussing examples of self-policing by open-source communities).

266. *See id.* at 80.

267. *See id.* at 73.

A. DIYbio

1. The Current Approach: Primarily Self-Regulation

To date, governance of DIYbio has relied heavily on a form of self-regulation. Community labs have played a critical role in addressing potential hazards. DIYbio participants in these labs have formulated ethical principles, and the DIYbio community has partnered with the FBI to learn about and identify potential threats. Thus, the current approach relies on norms and architecture rather than law.

Much—but not all—DIYbio activity takes place in community labs.[268] Community labs generally regulate access and lab materials.[269] Lab directors, who might face legal liability should problems arise, typically "evaluate each new member and their project for safety."[270] Lab directors also approve the introduction and removal of materials from the lab.[271] Further, community labs typically require BSL-1 lab conditions, which do not allow for work with disease-causing organisms.[272] Persons working in BSL-1 conditions must follow basic lab safety practices and adhere to established codes of conduct.[273] Insurers—a nongovernment intermediary—also play a governance role by requiring documented adherence to safety rules.[274]

In a further effort to instill a culture of safety, the DIYbio community has developed rudimentary ethics codes.[275] Participants in a 2011 conference of DIYbio groups drafted a code that outlines principles in seven areas, including open access, safety, and the environment.[276] Nevertheless, the principles are rather general and, without further elaboration, may be too vague to provide concrete guidance in specific situations. For example, the principle governing

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268. *See* GRUSHKIN ET AL., *supra* note 4, at 6. Even if DIY biologists do not work specifically in a community lab, they typically work in "group spaces" instead of in isolation. *See id.* at 9 ("92 percent of DIYers work in group spaces. These split between community labs, group labs solely devoted to biotechnology, and electronics hackerspaces that house DIYbio labs.").

269. *See id.* at 19.

270. *Id.*

271. *Id.*

272. *See id.* at 15.

273. *See* CTRS. FOR DISEASE CONTROL & PREVENTION, *supra* note 33, at 30–32 (outlining BSL-1 "standard practices").

274. *See* Landrain et al., *supra* note 5, at 124.

275. GRUSHKIN ET AL., *supra* note 4, at 14; *Draft DIYbio Code of Ethics from North American Congress*, DIY BIO, https://diybio.org/codes/code-of-ethics-north-america-congress-2011/ [https://perma.cc/5RMR-E4JS].

276. *Draft DIYbio Code of Ethics from North American Congress*, *supra* note 275.

safety simply states, "[a]dopt safe practices."[277] Similarly, the principle governing the environment declares: "Respect the environment."[278] Nonetheless, advisory boards of community labs can expand upon these principles in specific contexts. A web portal, "Ask a Biosafety Expert," is also available to offer advice.[279]

A partnership with the FBI has enhanced and supplemented the DIYbio community's self-regulatory efforts to address biosecurity risks.[280] Mindful of potential biosecurity risks but also worried that a heavy-handed approach might drive DIYbio activity underground, the FBI established an outreach program.[281] Through the program, the FBI sought to gain the trust of DIYbio members and to secure their assistance as potential informants.[282] As the FBI's relationship with the DIYbio community grew, the FBI convinced the community that collaboration with the FBI would counter a growing public mistrust of community lab experiments, while DIY biologists persuaded the FBI that their community lab activities generally pose a minimal threat to biosecurity.[283] The resulting partnership has provided the government with access to expertise and assistance in policing potential threats at a relatively low cost.[284]

Further consideration of the ability of community labs to govern DIYbio's risks is appropriate, given their central role. By analogy, one might look to more well-established research institutions that

277. *Id.*

278. *Id.*

279. *Ask a Biosafety Professional Your Question*, DIYBIO, http://ask.diybio.org/ [https://perma.cc/H9JT-P3B7].

280. *See* PRESIDENTIAL COMM'N FOR THE STUDY OF BIOETHICAL ISSUES, *supra* note 30, at 146; Tocchetti & Aguiton, *supra* note 34, at 829, 844.

281. *See* Tocchetti & Aguiton, *supra* note 34, at 829.

282. *See id.*; Kellogg, *supra* note 9, at 21, 25–26; *see also* NAT'L SCI. ADVISORY BD. FOR BIOSECURITY, STRATEGIES TO EDUCATE AMATEUR BIOLOGISTS AND SCIENTISTS IN NON-LIFE SCIENCE DISCIPLINES ABOUT DUAL USE RESEARCH IN THE LIFE SCIENCES 1 (2011), https://osp.od.nih.gov/biotechnology/nsabb-reports-and-recommendations/ [https://perma.cc/Y56P-2SN8] (recommending specific education and outreach efforts in response to observations gathered from "non-traditional audiences" in the life-science community).

283. *See* Tocchetti & Aguiton, *supra* note 34, at 833–45; *see also* DELFANTI, *supra* note 17, at 116. The FBI has experienced greater success in establishing relationships with the American DIYbio community than with the European DIYbio community, who have been wary of the FBI's overtures. *See* Howard Wolinsky, *The FBI and Biohackers: An Unusual Relationship*, 17 EMBO REPS. 793, 793–95 (2016), http://onlinelibrary.wiley.com /doi/10.15252/embr.201642483/full [https://perma.cc/HB5U-D78S (dark archive)].

284. *See* Snow, *supra* note 1, at 64–65; *see also* Tocchetti & Aguiton, *supra* note 34, at 843 (concluding that collaboration has expanded "[t]he biosecurity apparatus . . . from the sphere of state, military, and corporations to reach out to individuals and nonstate actors (i.e., graduate and postgraduate students, dropouts, members of the civil society, and disenfranchised scientists)").

perform similar oversight functions for professional scientists. Unfortunately, oversight by such institutions raises concerns regarding whether professional scientists—let alone DIY biologists—operate with adequate safeguards. University and corporate research institutions have lab rules, local oversight committees, and other mechanisms to foster responsible practices and address potential risks.[285] However, even these institutions sometimes lack the expertise, independence, and authority to regulate effectively.[286] Deficiencies in preparedness, training, and adherence to safety protocols periodically contribute to serious accidents in these institutional settings.[287] Indeed, a 2014 National Academy of Sciences report noted that some researchers view safety practices "as a barrier to research progress and a violation of their academic freedom."[288] It would not be surprising for such views also to exist within the DIYbio community, which espouses as a core value the freedom to experiment outside of traditional research settings.[289]

In response to such concerns, DIY biologists point to a culture of openness and responsibility. Codes of conduct and community-based oversight can help guard against mishaps and deliberate misuse of the technology.[290] Further, the FBI's outreach program enables some monitoring of DIYbio's biosecurity risks, though perhaps not its ecological risks.[291] Nonetheless, the self-identification of many DIYbio practitioners as "biohackers"[292] suggests the difficulty of effective control through such efforts. Hacker culture, though heterogeneous and dynamic, is generally characterized as having a "communal ethos . . . with values such as free sharing of information

285. *See* PRESIDENTIAL COMM'N FOR THE STUDY OF BIOETHICAL ISSUES, *supra* note 30, at 143, 146.

286. *See* Megan J. Palmer, Francis Fukuyama & David A. Relman, *A More Systematic Approach to Biological Risk*, 350 SCI. 1471, 1472 (2015).

287. *See* NAT'L ACAD. OF SCIS., SAFE SCIENCE: PROMOTING A CULTURE OF SAFETY IN ACADEMIC CHEMICAL RESEARCH 9, 15 (2014) (discussing chemical laboratory accidents that have occurred in institutional settings); *see also* CTRS. FOR DISEASE CONTROL & PREVENTION, *supra* note 33, at 6 (noting that laboratory-associated infections from exposure to biological agents are infrequent but continue to occur).

288. NAT'L ACAD. OF SCIS., *supra* note 287, at 3.

289. *See* Kellogg, *supra* note 9, at 21 (emphasizing the importance of freedom for amateur scientists and hobbyists hoping to make breakthroughs in non-traditional research settings).

290. *See supra* notes 268–79 and accompanying text.

291. *See* Kellogg, *supra* note 9, at 26 (quoting FBI policy and a program specialist's characterization of the FBI's mission as protecting the DIYbio community from exploitation and enabling community to proceed with research).

292. *See* DELFANTI, *supra* note 17, at 111, 117; MARCUS WOHLSEN, BIOPUNK: DIY SCIENTISTS HACK THE SOFTWARE OF LIFE 5 (2011).

and knowledge, and peer recognition."[293] In general, these features could enable codes of conduct to work.[294] Yet also prominent in hacker culture are distrust of authority, rebellion against established institutions, and opposition to code restrictions.[295] Any form of external oversight—whether through government regulation, community lab rules, or codes of conduct—may be viewed as contrary to the hacker ethos. Nor are such attitudes limited to DIY biologists tinkering with lab experiments. Bio-artists, who use DIYbio to create living works of art, may similarly oppose rules and instead seek fame, or notoriety, through shocking creations.[296]

DIYbio's antiestablishment approach is expressed primarily "as a challenge to BigBio—the ensemble of big corporations, global universities and international and government agencies that compose the economic system of current life sciences."[297] But the same attitude could be turned against the DIYbio community itself, which one biohacker has described as "hierarchical and exclusive."[298] Moreover, the hacker culture embraces widespread participation and the unencumbered pursuit of research.[299] In the context of DIYbio, anyone with the desire and enthusiasm to tinker with DNA is invited to engage in experimentation, to "just do it"—no PhD, peer-review process, or expert committee oversight required.[300]

293. DELFANTI, *supra* note 17, at 56.

294. *See id.*; WOHLSEN, *supra* note 292, at 80–81; *see also* STEVEN LEVY, HACKERS: HEROES OF THE COMPUTER REVOLUTION 26–36 (1984) (describing principles of the "Hacker Ethic").

295. *See* DELFANTI, *supra* note 17, at 60, 64; Gabriela A. Sanchez Barba, We Are Biohackers: Exploring the Collective Identity of the DIYbio Movement, at 41 (Aug. 2014) (unpublished M.S. thesis, University of Geneva), https://www.researchgate.net/publication/284727537_We_are_Biohackers_Exploring_the_Collective_Identity_of_the_DIYbio_Movement [https://perma.cc/553Y-7UHU (staff-uploaded archive)] ("Biohackers . . . strongly object to imposed requirements and restrictions of any kind that may exclude people from access and participation or infringe on their freedom of inquiry").

296. *See* WOHLSEN, *supra* note 292, at 201–02; Charo & Greely, *supra* note 20, at 13 (explaining the potential unlimited bounds of bio-art and the tendencies of such artists "to achieve fame through sometimes shocking transgressions").

297. *See* DELFANTI, *supra* note 17, at 4.

298. Steph Yin, *Is DIY Kitchen CRISPR a Class Issue?*, POPULAR SCI. (May 3, 2016), http://www.popsci.com/is-bringing-crispr-to-kitchens-class-issue [perma.cc/S8X8-NXLM] (quoting Josiah Zayner, who is offering do-it-yourself CRISPR kits for sale to home hobbyists).

299. *See* DELFANTI, *supra* note 17, at 4, 118 ("Hackers do not always like the sunlight.").

300. *See* Ana Delgado, *DIYbio: Making Things and Making Futures*, 48 FUTURES 65, 65, 69 (2013); Sanchez Barba, *supra* note 295, at 35, 41 (reporting comment that "in DIYbio no one has to justify things in terms of profits or generating new knowledge, 'you can explore things just for fun'").

As the technology becomes cheaper and easier to use, DIYbio is unlikely to remain confined in community labs. Already, one DIY biologist is marketing a $120 gene modification kit for home use that incorporates the powerful CRISPR gene-editing technology.[301] While its applications are limited, the kit foreshadows potential future developments.[302] Moreover, as even codes of conduct advocates concede, "community norms will have little effect on the behaviour of rogue individuals who are intent on causing mischief or harm."[303]

Community lab oversight and other forms of self-regulation may be especially deficient in addressing ecological concerns. Inherent in DIYbio is a quest to improve upon nature.[304] Further, as noted above, DIYbio promotes experimentation outside of conventional constraints. In this cultural context, DIY biologists might well pass over ecological concerns, notwithstanding the code of conduct's admonition to "respect the environment."[305] The developers of the Glowing Plant project made statements exemplifying this casual attitude towards the natural environment. Without consulting any ecologists, the developers declared that widespread release of the engineered plants would cause no environmental harm.[306] And in response to an interview query regarding the desirability of a completely bioengineered world, one co-developer simply remarked that the world is already engineered.[307] Such sentiments suggest the limitations of a community lab-centered approach and the need to consider additional means of governance.

301. *See* Lisa M. Krieger, *Bay Area Biologist's Gene-Editing Kit Lets Do-It-Yourselfers Play God at the Kitchen Table*, MERCURY NEWS (Jan. 11, 2016), https://www.mercurynews.com/2016/01/11/bay-area-biologists-gene-editing-kit-lets-do-it-yourselfers-play-god-at-the-kitchen-table/ [https://perma.cc/25T5-KYDL]. For further discussion of CRISPR, see *supra* note 15 and accompanying text.

302. *See* Krieger, *supra* note 301.

303. Kuiken, *supra* note 16, at 168.

304. *See* Sanchez Barba, *supra* note 295, at 2 (discussing the emergence of the DIYbio movement and the various roles that the movement seeks to play in the fields of life science and technology).

305. *Draft DIYbio Code of Ethics from North American Congress*, *supra* note 275.

306. *See* Jozef Keulartz & Henk van den Belt, *DIY-Bio—Economic, Epistemological and Ethical Implications and Ambivalences*, LIFE SCI. SOC'Y & POL'Y, May 2016, at 1, 14.

307. *See id.*; *cf.* Snow, *supra* note 1, at 36 (reporting that a biohacker working on genetically modifying plants to survive increased radiation commented: "My plan is to make it first and ask questions later.").

2. Applying Big Data/Big Government and Nongovernment Intermediary Approaches to DIYbio

At first glance, applying a Big Data/Big Government approach to DIYbio would seem daunting. Overseeing DIYbio research activity is inherently more difficult than overseeing research in universities, corporate laboratories, and other institutions.[308] The prospect of keeping genetic material secure in a limited number of controlled environments, while plausible in the past, appears no longer feasible in light of technological advances.[309] The FBI has avoided an aggressive law-and-order approach in order to avoid driving DIYbio activity underground,[310] and no obvious technology exists to detect whether someone is engaging in DIYbio within the confines of his or her own home.

Nonetheless, a Big Data/Big Government approach may be practicable. Such an approach may include, for example, mandates for biosafety training or personal liability insurance or a requirement that DIY biologists register with the government.[311] Creating a registry for DIY biologists would be a sensible first step.[312] A registry would gather information regarding who is engaging in DIYbio and how they are engaging in it while imposing limited burdens on DIY biologists and the government. A registration requirement could be enforced by prohibiting suppliers from selling CRISPR kits and other genetic material to unregistered persons.[313] Having additional information about ongoing DIYbio activity would enable better assessment of potential risks and the need to develop further measures.

Such a registry might resemble the Federal Aviation Administration ("FAA") registry for small unmanned aircraft (i.e., drones).[314] In response to a congressional mandate to integrate unmanned aircraft into the national airspace system,[315] the FAA developed registration requirements to enable rapid identification of

308. *See* Greely, *supra* note 15.

309. *See* Palmer et al., *supra* note 286, at 1471.

310. *See* Tocchetti & Aguiton, *supra* note 34, at 834–36.

311. *See* Kellogg, *supra* note 9, at 26 (noting various proposals for a more direct regulatory approach for DIYbio).

312. *See* E-mail from Hank Greely, Professor of Law, Stanford Law Sch., to author (May 27, 2016) (on file with the North Carolina Law Review).

313. *See id.*

314. Hank Greely suggested this analogy. *Id.*

315. *See* FAA Modernization and Reform Act of 2012, Pub. L. No. 112-95, § 332, 126 Stat. 11, 73 (codified at 49 U.S.C. § 40101 (2015)).

drones and to educate drone owners on safety requirements.[316] Concluding that the paper-based registration requirements generally applicable to aircraft owners would be too onerous if applied to small drone operators, the FAA developed a streamlined, web-based registration process specific to small unmanned aircraft owners.[317] Any person who owns an unmanned aircraft between fifty-five hundredths of a pound and fifty-five pounds must comply with registration requirements.[318] Registered owners are assigned a registration number, which must be marked on all aircraft,[319] and must provide proof of registration if requested by law enforcement or the FAA.[320] Owners are not required to take a test or otherwise prove they know how to operate a drone, however.[321]

Experience with drone registration to date suggests that enforcing an analogous registration requirement for DIYbio would face significant challenges. Notwithstanding the threat of substantial civil or criminal penalties for noncompliance, hundreds of thousands of drone owners apparently missed the registration deadline.[322] The FAA has encouraged state and local law enforcement agencies to

316. Registration and Marking Requirements for Small Unmanned Aircraft, 80 Fed. Reg. 78,594, 78,594–95 (Dec. 16, 2015) (to be codified at 14 C.F.R. pt. 48); *see also* Interpretation of the Special Rule for Model Aircraft, 79 Fed. Reg. 36,172, 36,172 (June 25, 2014) (to be codified at 14 C.F.R. pt. 91) (clarifying the FAA's authority to regulate unmanned model aircraft that endanger safety of national airspace).

317. Registration and Marking Requirements for Small Unmanned Aircraft, 80 Fed. Reg. at 78,595.

318. 14 C.F.R. § 48.15 (2017); Registration and Marking Requirements for Small Unmanned Aircraft, 80 Fed. Reg. at 78,594–95. Unmanned aircraft exceeding fifty-five pounds are subject to more extensive registration requirements. *See Beyond the Basics*, FED. AVIATION ADMIN., https://www.faa.gov/uas/beyond_the_basics/#55 (last modified Nov. 24, 2017, 4:16 PM) [https://perma.cc/43RB-VCMY] ("To fly a [unmanned aircraft] that weighs 55 lbs. or more, operators will need to use the existing Section 333 exemption process . . . .").

319. 14 C.F.R. § 48.200.

320. FED. AVIATION ADMIN., LAW ENFORCEMENT GUIDANCE FOR SUSPECTED UNAUTHORIZED UAS OPERATIONS 5 (2017), https://www.faa.gov/uas/resources/law_enforcement/media/FAA_UAS-PO_LEA_Guidance.pdf [https://perma.cc/J78J-ER97].

321. *See* Jacob Pramuk, *Why Registry May Not Make Drones Much Safer*, CNBC (Jan. 20, 2016), https://www.cnbc.com/2016/01/20/faa-drone-registry-may-not-be-enough.html [https://perma.cc/CNU2-NEEP].

322. *See* Jacob Pramuk, *Unregistered Drone Users May Face Jail Time*, CNBC (Feb. 23, 2016), http://www.cnbc.com/2016/02/23/unregistered-drone-users-may-face-jail-time.html [https://perma.cc/CL8C-4EJF]. The FAA warns that it may take enforcement action in the form of warning notices, letters of correction, or civil penalties "against anyone who conducts an unauthorized [drone] operation." FED. AVIATION ADMIN., *supra* note 320, at 5.

assist in detecting and enforcing against unauthorized drone operations,[323] but these agencies' resources are limited.

For DIYbio, a possible locus for enforcing a registration requirement is DNA synthesis companies, which could limit sales to registered persons.[324] Such an approach would combine a Big Data/Big Government approach with reliance on nongovernmental intermediaries. The federal government already encourages DNA synthesis companies to screen customers to confirm their identity and to screen gene sequences against a limited database of toxins and dangerous biological agents.[325] The viability of enforcing registration requirements through DNA synthesis companies assumes limited access to DNA synthesizers, however. Such an assumption is increasingly questionable in an era when DIY biologists can order custom DNA sequences on the internet or buy their own desktop DNA synthesizers.[326]

Community labs also could insist on registration as a condition of access. The FBI's outreach efforts already have laid a foundation for further collaboration with the DIYbio community. Community labs generally have expressed a desire to demonstrate to the public that they are operating safely,[327] so they might volunteer to enforce a registration requirement. Although enforcement through community labs would not reach lone-wolf experimenters, it could play an important role in registering most DIY biologists.

Another possible enforcement locus is the United States Patent and Trademark Office, which could require DIYbio patent applicants

323. FED. AVIATION ADMIN., *supra* note 320, at 5–7.

324. *See* E-mail from Hank Greely, *supra* note 312; *see also* Michele S. Garfinkel et al., *Synthetic Genomics: Options for Governance*, 3 INDUS. BIOTECHNOLOGY 333, 346–47 (2007) (discussing various options for DNA synthesis firms to act as a potential intervention point in screening DNA orders from end users prior to synthesis).

325. U.S. DEPT. OF HEALTH & HUM. SERVS., SCREENING FRAMEWORK GUIDANCE FOR PROVIDERS OF SYNTHETIC DOUBLE-STRANDED DNA 4 (2010); *see also* Ali Nouri & Christopher F. Chyba, *DNA Synthesis Security*, *in* GENE SYNTHESIS: METHODS AND PROTOCOLS 285, 290–91 (Jean Peccoud ed., 2012) (discussing potential future safeguards such as "built-in software or hardware that screens DNA sequence inputs and compares them to the sequences of pathogens and toxins of concern"). *See generally* Jonathan B. Tucker, *Double-Edged DNA: Preventing the Misuse of Gene Synthesis*, 26 ISSUES SCI. & TECH. 23 (2010) (recounting the historical development of industry self-regulation and government guidelines for screening by DNA synthesis companies).

326. *See* Nouri & Chyba, *supra* note 325, at 289 (noting potential for "diffusion of advanced synthesizers—those capable of constructing large DNA molecules—to individual users around the world"); *see also* Michele Garfinkle & Lori Knowles, *Synthetic Biology, Biosecurity, and Biosafety*, *in* ETHICS AND EMERGING TECHNOLOGIES 533, 534 (Ronald L. Sandler ed., 2014).

327. *See* Tocchetti & Aguiton, *supra* note 34, at 834, 844.

to prove they have fulfilled all legal requirements for conducting DIYbio activity before issuing a patent.[328] This potential enforcement mechanism seems less promising, however, as it would reach only those persons who go forward with the patenting process. Relatively few DIY biologists are likely to seek patents, given the movement's ethos of open access and its general hostility to intellectual property regimes.[329] Would-be bioterrorists, amateurs who simply want to tinker, and open source enthusiasts would be indifferent to the threat of unpatentability.

Government also could adopt approaches that incorporate financial incentives, for example, by funding DIYbio labs. Subsidies are frequently used to incentivize activities that provide public benefits,[330] and conditions placed on government funding recipients historically have played an important role in research oversight. Government-sponsored DIYbio labs could provide data to the government and enable oversight, while at the same time encouraging innovative experimentation.[331] Moreover, inexpensive access to such labs may help keep DIYbio outside of private spaces where unsafe or unsupervised experiments may be more likely.[332] Political support for government-funded DIYbio labs, however, may be hard to come by if public benefits are not obvious.[333] Furthermore, DIYbio practitioners, sensitive to threats to freedom of inquiry, may view any government

328. Kellogg, *supra* note 9, at 26 ("In such a case, any patent applicant would need to prove he or she had gone through biosafety training, has insurance, or hadn't spent time in prison.").

329. *See supra* notes 292–96 and accompanying text.

330. *See* Rauch & Schleicher, *supra* note 73, at 950–51 (explaining how various municipalities subsidize the "sharing economy" through urban bike-shares, direct payments to "sharing firms" like Uber, and other subsidies); *see also* ORSI ET AL., *supra* note 229, at 9–37 (describing steps that municipalities can take to promote sharing activities, including designated parking for car sharing and support for housing and worker cooperatives).

331. *See* GRUSHKIN ET AL., *supra* note 4, at 22 (advocating for publicly funded community labs to drive innovation in DIYbio and improve enforcement capabilities).

332. *See* Holloway, *supra* note 28, at 28 ("Providing formal laboratory space . . . helps keep DIYbio outside of garages and suburban homes while also providing the education needed to ensure that appropriate laboratory procedures—and any future regulations—are followed."); *see also* Landrain et al., *supra* note 5, at 124 (explaining how public community labs would improve safety and potential enforcement of regulations).

333. *Cf.* Chad Orzel, *The Most Important Science to Fund Is the Hardest to Explain*, FORBES (Mar. 23, 2017), https://www.forbes.com/sites/chadorzel/2017/03/23/the-most-important-science-to-fund-is-the-hardest-to-explain/#b8acd0f27179 [https://perma.cc/FP6U-D3AC] (describing historical criticism of scientific research funding that is difficult to understand as wasteful).

involvement as a threat to co-opt their movement.[334] Persons seeking to avoid government oversight through these labs might turn to crowdfunding or other forms of private sponsorship.[335] In addition, the declining costs of DIYbio experimentation will allow some to fund their own labs rather than rely on government facilities.

Finally, it may eventually be possible to incorporate controls through code. DIY biologists someday could find it easier to work with standardized biological systems rather than to start projects from scratch.[336] If so, security features might be incorporated into components used by DIY biologists.[337] Similarly, synthetic biologists might one day design a genetic code containing synthetic nucleic acids, use of which would prevent genetic interactions with natural biological systems.[338] Other proposed biological containment mechanisms include the development of organisms dependent on artificial substances not found in nature.[339] The nongovernment intermediaries who design these mechanisms essentially would function as gatekeepers or risk managers for DIY biologists' experiments involving these mechanisms. For now, however, such mechanisms are best described as speculative, and even if eventually developed, they would have their own limitations and risks.[340]

In sum, a registration requirement for DIY biologists would be a relatively undemanding way for the government to gather information regarding ongoing activity and determine the need for additional oversight. Enforcing such a requirement through community labs and suppliers of genetic materials would build on existing procedures and enable coverage of most DIY biologists.

334. *See* Sanchez Barba, *supra* note 295, at 44–45 (noting hacker resistance to DARPA funding the expansion of the hackerspace model in United States high schools).

335. *See* NAT'L ACADS. OF SCIS., ENG'G & MED., *supra* 103, at 33–34 (suggesting potential for crowdfunding or other private investment to place biotechnology activities outside biosafety oversight mechanisms).

336. *See* Landrain et al., *supra* note 5, at 116, 124.

337. *Id.* at 124.

338. *See* Markus Schmidt & Víctor de Lorenzo, *Synthetic Constructs in/for the Environment: Managing the Interplay Between Natural and Engineered Biology*, 586 FEBS LETTERS 2199, 2201–03 (2012).

339. Bernadette Bensaude Vincent, *Ethical Perspectives on Synthetic Biology*, 8 BIOLOGY THEORY 368, 371 (2013); *see also* Schmidt & de Lorenzo, *supra* note 338, at 2201–03.

340. *See* Schmidt & de Lorenzo, *supra* note 338, at 2204.

B. 3D Printing

1. A Potential Big Data/Big Government Approach

3D printing is presently subject to little oversight, with the exception of specific classes of products such as drugs and medical devices that are subject to regulation regardless of how they are made.[341] Technological advances, however, could enable application of a Big Data/Big Government approach to 3D-printed products. For example, researchers have reverse-engineered 3D-printed objects using sounds emitted by a 3D printer.[342] 3D-printing activity generates not only sound but also a thermal profile and electromagnetic radiation, each of which provides potential clues regarding the object being printed.[343] Surveillance of 3D-printing activity could also rely on other ways to gather data, as 3D printers typically have cameras and connections to Wi-Fi networks.[344] Users generally conduct at least some part of their activity online, whether uploading or downloading digital files, sending files to a maker-hub, or using cloud-based design software.[345] As a result, government has multiple potential entry points for monitoring and regulating 3D-printing activity.

A Big Data/Big Government approach could involve mere surveillance or more direct regulation. Direct regulation might focus on the possession of digital files for manufacturing a dangerous object or on the possession of the object itself.[346] 3D printing relies on digital files that could be tracked—at least in theory. Alternatively, a license might be required to own a 3D printer or to introduce 3D-printed objects into commerce.[347] Enforcement of such requirements may be

341. *See, e.g.*, Technical Considerations for Additive Manufactured Devices, 81 Fed. Reg. 28,876, 28,877 (May 10, 2016) (providing the "FDA's initial thoughts" on how it would regulate additive manufacturing); Ahmed Zidan, *CDER Researchers Explore the Promise and Potential of 3D Printed Pharmaceuticals*, U.S. FOOD & DRUG ADMIN., https://www.fda.gov/Drugs/NewsEvents/ucm588136.htm [https://perma.cc/Y5NE-24KV] (last updated Dec. 11, 2017) (reporting that the FDA has approved approximately 200 3D-printed devices).

342. Mara Hvistendahl, *3D Printers Vulnerable to Spying*, 352 SCI. 132, 132 (2016).

343. *Id.* at 133.

344. Tracy Hazzard & Tom Hazzard, *3D Print Spying: How Your Printer Poses a Security Risk*, 3D START POINT (Apr. 26, 2016), http://3dstartpoint.com/3d-print-spying/ [https://perma.cc/F4UM-A47P].

345. LUKE HEEMSBERGEN ET AL., MELBOURNE NETWORKED SOC'Y INST., 3D PRINTING: CIVIC PRACTICES AND REGULATORY CHALLENGES 28 (2016).

346. *See* CASTRO, *supra* note 57, at 4.

347. *See id.* at 5 (characterizing a license requirement as "unlikely and ill-advised because of . . . its intrusiveness and complexity"); *see also* HEEMSBERGEN ET AL., *supra* note 345, at 38 (discussing licensing proposal).

difficult, however. In some instances, the targets of data collection or regulatory efforts may be able to mask information by creating physical barriers to detection, inserting white noise, or encrypting digital files.[348]

Moreover, as is often true of a Big Data/Big Government approach, government surveillance of 3D printing could be intrusive or even unconstitutional. The Supreme Court has held that the use of thermal imaging to measure heat emanating from a home is a search governed by the Fourth Amendment.[349] Inside and outside the home, however, many unanswered questions remain regarding how the Fourth Amendment might apply to various technologies.[350] Efforts to regulate possession of information would likely run into First Amendment objections as well.[351]

Furthermore, a too-aggressive Big Data/Big Government approach could backfire by driving activity underground. For example, as a result of the Department of State's efforts to restrict online publication of 3D-printed gun designs, "online groups that had been openly discussing 3D printing firearms suddenly instituted private chat rooms, deleted comments on how to meet existing gun laws or ways to circumvent the law, and began looking to encryption programs or Dark Web servers sponsored by foreign entities to escape US jurisdiction."[352] In this instance, heavy-handed regulation complicated information gathering, decreased users' willingness to cooperate with the government, and arguably hastened further dissemination of 3D-printed gun designs.[353]

A similar reaction likely would follow stringent government efforts to limit the distribution or printing of other 3D designs. Like their counterparts in the DIYbio community, many 3D-printing enthusiasts subscribe to the hacker ethic and generally oppose restrictions on their activities.[354] "Information wants to be free"—a

348. *See* Hvistendahl, *supra* note 342, at 133.

349. *See* Kyllo v. United States, 533 U.S. 27, 34–40 (2001).

350. *See* Emma Raviv, *Homing In: Technology's Place in Fourth Amendment Jurisprudence*, 28 HARV. J.L. & TECH. 593, 608–16 (2015) (discussing application of "reasonable expectation of privacy standard" developed in Katz v. United States, 389 U.S. 347 (1967), to various technologies). *See generally* Olivier Sylvain, *Failing Expectations: Fourth Amendment Doctrine in the Era of Total Surveillance*, 49 WAKE FOREST L. REV. 485 (2014) (contending that reasonable expectation standard inadequately protects privacy in context of modern technologies).

351. *See* CASTRO, *supra* note 57, at 4.

352. Snow, *supra* note 1, at 44.

353. *See id.*

354. *See* ANGELA DALY, SOCIO-LEGAL ASPECTS OF THE 3D PRINTING REVOLUTION 10–11 (2016).

notion that underlies digital file sharing practices and permeates the internet generally—is a popular theme in the world of 3D printing, heralding for some the democratization of invention and production.[355] Accordingly, 3D-printer users would likely resist regulation and develop mechanisms to circumvent it.

2. Nongovernmental Intermediaries

Ultimately, reliance on intermediaries is likely to be an important element of any 3D-printing oversight. Websites or other entities that host and distribute information could be involved in policy development, information gathering, standard setting, and enforcement.[356] Indeed, enforcement of any limitations on publishing or disseminating 3D-printing files would be far easier against these entities than against individual website users.[357] For example, Thingiverse, a widely used website for sharing digital design files, has an "acceptable use" policy that forbids users from collecting or distributing any content that violates a third party's intellectual property right or that "promotes illegal activities or contributes to the creation of weapons, illegal materials or is otherwise objectionable."[358] While websites might adopt such policies on their own, government also might mandate that website owners remove certain types of files under a notice-and-takedown regime similar to that applied to copyrighted material under the Digital Millennium Copyright Act.[359] Websites beyond the jurisdiction of the United

355. *See id.* at 8–11; *see also* R. Polk Wagner, *Information Wants to Be Free: Intellectual Property and the Mythologies of Control*, 103 COLUM. L. REV. 995, 1002–05 (2003).

356. Relatedly, online feedback can help address safety risks related to 3D-printed products. Osborn, *supra* note 36, at 596–97. Purchasers of 3D-print files or 3D-printed items can post reviews or provide feedback to designers. *Id.* at 597.

357. *See* CASTRO, *supra* note 57, at 4. Direct enforcement against 3D-printing end users may be no more successful than against sharers of music and movie files. *See* Max Marder, *Leave 3D Printing Alone*, HUFFINGTON POST: THE BLOG (Dec. 06, 2017), http://www.huffingtonpost.com/the-morningside-post/leave-3d-printing-alone_b_4666660.html [https://perma.cc/NL72-K5V4].

358. *MakerBot Terms of Use* at ¶ 3.3, MAKERBOT, https://www.makerbot.com/legal/terms [https://perma.cc/5R92-BKZX] (last updated Oct. 17, 2017). Although labeled as "MakerBot Terms of Use," the terms also cover Thingiverse, as MakerBot owns the website. *Id.*

359. Digital Millennium Copyright Act of 1998, Pub. L. No. 105-304, sec. 202, § 512(c)(1)(C), 112 Stat. 2860, 2879–80 (codified as amended at 17 U.S.C. § 512(c)(1) (2012)); *see* Desai & Magliocca, *supra* note 62, at 1718 (proposing enactment of notice-and-takedown regime for websites that host 3D-printing files); CASTRO, *supra* note 57, at 4; *see also* 17 U.S.C. § 512(c) (2012). Under the Digital Millennium Copyright Act, an internet service provider can avoid potential liability for copyright infringement by removing an allegedly infringing item from its servers upon receipt of a proper takedown

States would likely be able to evade such a mandate, however.[360] In addition, just as peer-to-peer networks for sharing digital music files undermined copyright enforcement efforts aimed at intermediaries, users would likely develop mechanisms to circumvent 3D-printing mandates aimed at website intermediaries.[361]

Another possible locus of oversight is at the level of 3D-printer manufacturers. Requiring manufacturers to incorporate mechanisms to reduce health and safety hazards would be one logical mandate. But printer manufacturers could be asked to address concerns regarding counterfeit or dangerous 3D-printed objects as well. For example, manufacturers might be required to build 3D printers such that they embed a traceable identifier, such as a pattern of microbubbles, within all 3D-printed objects they create.[362] Alternatively, 3D-printer software could require an identification code in order to print a file or could block the printing of certain types of files.[363] Such architecture-based efforts to limit the printing capability of 3D printers, however, may encounter resistance from users and manufacturers and prove vulnerable to hacking.[364] In addition, the ability of individuals to construct 3D printers on their own[365] could render such oversight ineffectual.

3. Self-Regulation

Finally, self-regulation by 3D-printer users offers another, perhaps less promising, option for managing risks. Self-regulation might take the form of restrictions embedded within code or voluntary guidelines developed and disseminated by companies or individuals engaged in 3D printing.[366] For example, one commentator has proposed that users follow a norm of taking a screenshot of an item before printing it in order to promote transparency and

notice. *See* Lydia Pallas Loren, *Deterring Abuse of the Copyright Takedown Regime by Taking Misrepresentation Claims Seriously*, 46 WAKE FOREST L. REV. 745, 747 (2011).

360. *See* CASTRO, *supra* note 57, at 4.

361. *See* Osborn, *supra* note 36, at 616.

362. *See* Wren, *supra* note 53; *see also* CASTRO, *supra* note 57, at 5.

363. *See* Osborn, *supra* note 36, at 603.

364. *See* Desai & Magliocca, *supra* note 62, at 1715.

365. Rae Ellen Bichell, *For a Few Hundred Bucks, You Can Make Your Own 3-D Printer*, NAT'L PUB. RADIO: ALL TECH CONSIDERED (Nov. 12, 2013), http://www.npr.org/sections/alltechconsidered/2013/11/08/243951594/for-a-few-hundred-bucks-you-can-make-your-own-3-d-printer [https://perma.cc/9KG8-TEVE (staff-uploaded archive)].

366. *See* Osborn, *supra* note 36, at 603 (discussing the "use [of] code for regulatory purposes in the 3D printing context"); Adam D. Thierer & Adam Marcus, *Guns, Limbs, and Toys: What Future for 3D Printing?*, 17 MINN. J.L. SCI. & TECH. 805, 829 (2016).

accountability.[367] Nevertheless, in the instances when oversight is most needed—such as the printing of contraband—users are unlikely to follow such a norm. Furthermore, community-based oversight, which offers an external check on undesirable DIYbio activity, is less likely to be an effective check on undesirable 3D printing. Currently, most DIYbio activity occurs in community labs, making it subject to the formal and informal oversight of others. 3D printing, in contrast, can be undertaken more readily by individuals lacking technical expertise and within the privacy of one's home.[368] Thus, community–based oversight and norms are less likely to be successful in such a context.

Ultimately, a Big Data/Big Government approach to governing 3D printing may be tempting to adopt, but it would encounter significant practical and constitutional limitations. Websites and other nongovernmental intermediaries may serve as more effective and adaptable channels for governing 3D-printing products. In addition, to address the health and environmental impacts of the 3D-printing process, regulation of manufacturers may be necessary.

C. Sharing Economy

1. Experimenting with a Big Data/Big Government Approach

Of the distributed-innovation examples examined in this Article, the sharing economy is perhaps most susceptible to a Big Data/Big Government approach. Transactions in the sharing economy leave a digital trail that cash transactions do not.[369] Indeed, data collection and exchange are at the heart of the digital platforms that undergird the sharing economy. Though private digital platforms themselves collect and generate the data, governments could demand—and increasingly are demanding—the data for their own use.

A brief review of Uber's data collection practices hints at the vast quantity and range of information available. First, Uber collects personal information directly from each user.[370] Such information includes a user's name, email, phone number, postal address, and photo.[371] Furthermore, Uber collects usage information in a number of categories: contact information, including names and addresses in a

367. *See* HEEMSBERGEN ET AL., *supra* note 345, at 37–38.
368. Osborn, *supra* note 36, at 616.
369. *See* JOHAL & ZON, *supra* note 82, at 19.
370. *Privacy Policy*, UBER (Sept. 21, 2017), https://privacy.uber.com/policy [perma.cc/J2XD-RR88].
371. *Id.*

user's address books; information regarding a user's mobile devices; IP addresses, app features used, pages viewed, and other information available on server logs; credit card numbers and other transaction information; and information regarding a user's location.[372] Controversy has surrounded Uber's handling of user data, raising concerns regarding the company's use of the data, employee access to the data, data breaches, and user privacy.[373] Unsurprisingly, government officials have taken notice of Uber's treasure trove of data. State and local regulators, airport authorities, and law enforcement officials regularly request information from Uber about specific trips, trip routes, trip requests, vehicles, riders, and drivers.[374]

Governments have made liberal use of such data to enact regulatory schemes tailored to sharing-economy transactions. For example, local jurisdictions have adopted a variety of approaches to regulate pre-arranged transportation services.[375] Notably, these regulations largely focus on the transportation network companies ("TNCs"), such as Uber, that match drivers and passengers. For the most part, TNCs—and not individual drivers—are responsible for conducting criminal background checks, providing proof of insurance,

372. *See id.* Uber previously tracked users' location even when they were not using the app, but the company changed its policy to allow users to limit collection of such data to only when the app is used. *See* Selena Larson, *Uber to Give Users Better Control over Location Data*, CNN TECH (Aug. 29, 2017, 3:40 PM), http://money.cnn.com/2017/08/29/technology/uber-location-data/index.html [https://perma.cc/R9E5-5MVH]; Laura Roman, *Uber Now Tracks Passengers' Locations Even After They're Dropped Off*, NAT'L PUB. RADIO: ALL TECH CONSIDERED (Dec. 1, 2016, 6:08 PM), http://www.npr.org/sections/alltechconsidered/2016/12/01/503985473/uber-now-tracks-passengers-locations-even-after-theyre-dropped-off [https://perma.cc/R6B7-9JWK (staff-uploaded archive)].

373. *See* Eric Newcomer, *Uber Paid Hackers to Delete Stolen Data on 57 Million People*, BLOOMBERG TECH. (Nov. 21, 2017, 4:58 PM), https://www.bloomberg.com/news/articles/2017-11-21/uber-concealed-cyberattack-that-exposed-57-million-people-s-data [https://perma.cc/B433-NE4X]; Anita Ramasastry, *Too Much Sharing in the Sharing Economy? Uber's Use of Our Passenger Data Highlights the Perils of Data Collection via Geolocation*, JUSTIA: VERDICT (Feb. 10, 2015), https://verdict.justia.com/2015/02/10/much-sharing-sharing-economy [https://perma.cc/KK75-JD2C]; Roman, *supra* note 372. Uber had previously been commended for steps it took to protect user privacy and provide greater transparency regarding government requests for information. NATE CARDOZO, KURT OPSAHL & RAINEY REITMAN, ELEC. FRONTIER FOUND., WHO HAS YOUR BACK?: PROTECTING YOUR DATA FROM GOVERNMENT REQUESTS 23–24 (6th ed. 2016) https://www.eff.org/files/2016/05/04/who-has-your-back-2016.pdf [https://perma.cc/G3WZ-AUL5].

374. *Transparency Report*, UBER (Apr. 14, 2017), https://transparencyreport.uber.com/ [https://perma.cc/V4EH-QJJ8] (listing regulators and law enforcement from various jurisdictions who required Uber to give them information from July to December 2016).

375. *See* K. Casey Strong, *When Apps Pollute: Regulating Transportation Network Companies to Maximize Environmental Benefits*, 86 U. COLO. L. REV. 1049, 1078–87 (2015) (discussing different regulatory approaches applied to transportation network companies in Colorado, California, and Seattle, Washington).

and meeting other regulatory requirements.[376] Short-term residential rentals have also attracted the regulatory attention of local governments, which in some cases have created new oversight schemes tailored to these markets.[377] These schemes tend to impose regulatory requirements on both the hosts offering the rental and the web platforms through which rentals are arranged.[378]

The development of regulatory regimes tailored to specific sharing-economy activities suggests an increasingly adaptive and experimental approach to government regulation. Other tools reflecting such an approach include: temporary waivers or exemptions from regulation, which allow economic activity to continue while regulators gather information and gain experience; sunset or regulatory review provisions, which require regulators to revisit standards previously adopted; and pilot programs, which test a regulatory approach on a small scale prior to broader implementation.[379] The devolution of policy questions to local governments, which has allowed municipalities to adopt a variety of regulatory responses to Airbnb and Uber, itself demonstrates an experimental approach to governance that exemplifies Justice Brandeis's laboratories of democracy.[380]

A Big Data/Big Government approach could be applied not only to sharing-economy activities but also to the innovation process

376. *See, e.g.*, CAL. PUB. UTIL. CODE § 5433 (West, Westlaw through 2017 Reg. Sess. laws) (describing the insurance requirements for TNCs operating in California); Decision Adopting Rules and Regulations to Protect Public Safety While Allowing New Entrants to the Transportation Industry at 3, Decision No. 13-09-045, Rulemaking No. 12-12-011 (Cal. Pub. Utils. Comm'n Sept. 19, 2013), 2013 WL 10230598, at *2 (requiring, among other things, that TNCs obtain a license from the California Public Utilities Commission, conduct criminal background checks on their drivers, and maintain commercial liability insurance policies).

377. *See* Miller, *supra* note 70, at 184–95 (describing efforts to regulate short-term residential rental market). Some jurisdictions have attempted to enforce ordinances prohibiting or limiting such rentals. *See* Lobel, *supra* note 65, at 128–29.

378. *See, e.g.*, S.F., CAL., ADMIN. CODE § 41A.5(g) (2018, Am. Legal Pub. Corp., through Mar. 8, 2018).

379. *See* JOHAL & ZON, *supra* note 82, at 22, 24; Sofia Ranchordás, *Innovation-Friendly Regulation: The Sunset of Regulation, the Sunrise of Innovation*, 55 JURIMETRICS 201, 218–19 (2015). Along the same lines are proposals that government agencies organize regulatory experiments involving new risky technologies. Matthew T. Wansley, *Regulation of Emerging Risks*, 69 VAND. L. REV. 401, 404 (2016); *see also* Ranchordás, *supra*, at 207, 220–22.

380. *See* Lobel, *supra* note 65, at 161; *see also* New State Ice Co. v. Liebmann, 285 U.S. 262, 311 (1932) (Brandeis, J., dissenting) ("It is one of the happy incidents of the federal system that a single courageous state may, if its citizens choose, serve as a laboratory; and try novel social and economic experiments without risk to the rest of the country.").

itself—i.e., the continuing invention of new digital marketplaces.[381] The dynamic nature of innovation poses particular challenges for government in terms of identifying trends, determining regulatory needs, and designing suitable responses. Prohibitions or restrictions targeting a particular platform might be readily circumvented by the creation of alternative platforms offering a similar service.[382] Nonetheless, the digital nature of these marketplaces renders them traceable, and the efforts of these marketplaces to attract users will likely make them visible to regulators as well.

2. A Governance Role for Nongovernmental Intermediaries

Governance of the shared economy is not limited to the Big Data/Big Government approach. Airbnb, Uber, TaskRabbit, and other platform companies are emerging as key regulatory intermediaries.[383] In the sharing economy, platform companies offer "access to the software, the matching algorithms, and a digital system of reputation and trust between their users."[384] These companies can react more quickly than public regulators to new developments in the sharing economy.[385] Moreover, because of the market power that various platforms have gained through their extensive networks,[386] platform companies often have substantial authority and the ability to set and enforce standards.[387]

As already noted, government may impose mandates on platforms in order to regulate distributed-innovation activity indirectly.[388] Yet platform companies may exercise a governance function even in the absence of public mandates. Platform companies are private, economically-motivated actors whose self-interests may prompt them to address certain aspects of market failures.[389] In addition, platform companies may be subject to pressure from angel

381. *See supra* note 65 and accompanying text.

382. *See* Miller, *supra* note 70, at 168 (noting the failed efforts to regulate the illegal music-sharing business by shutting down Napster).

383. *See* Cohen & Sundararajan, *supra* note 261, at 116–17 ("[P]latforms should not be viewed as entities to be regulated but rather as actors that are a key part of the regulatory framework . . . ."); *see also* BALARAM, *supra* note 64, at 37–38.

384. Lobel, *supra* note 65, at 100.

385. *See* Zale, *supra* note 74, at 1005–06.

386. *See* BALARAM, *supra* note 64, at 18–19.

387. *See* Cohen & Sundararajan, *supra* note 261, at 130.

388. *See supra* text accompanying notes 249–52.

389. *See* Cohen & Sundararajan, *supra* note 261, at 121.

investors and venture capitalists to adhere to specific rules or requirements as a condition of continued funding.[390]

Platform companies commonly reduce information asymmetries through online feedback systems, background checks, and screening of service providers.[391] They often address risks to users by offering money-back guarantees or liability insurance coverage.[392] And leery of public opposition or government regulation, platform companies may adopt measures to diminish the negative externalities associated with their users' activities. TaskRabbit has instituted a sitewide minimum wage,[393] for example, and Airbnb has created a hotline on its website for neighbors of Airbnb hosts.[394]

Reputations established through online feedback are a particularly prominent mechanism for governance in the sharing economy. Reputation systems improve market functioning by increasing the quality and quantity of information on which market participants base their decisions.[395] Providers are unlikely to attract business if their ratings are adverse, and users who develop a negative reputation may be excluded from subsequent transactions. Ratings systems provide information in a "real-time and dynamic" manner and "functionally substitute personal trust and regulated standards."[396] These systems, however, are not perfect. They can be subject to bias, manipulation, and falsification, and feedback mechanisms may magnify the effect of a few initial reviews, whether accurate or not.[397]

390. *See generally* Darian M. Ibrahim, *The (Not So) Puzzling Behavior of Angel Investors*, 61 VAND. L. REV. 1405 (2008) (discussing roles and behaviors of angel investors and venture capitalists and their non-financial motivations for investing).

391. *See* Cohen & Sundararajan, *supra* note 261, at 120–22; Lobel, *supra* note 65, at 147–48, 151–55.

392. FED. TRADE COMM'N, THE "SHARING" ECONOMY: ISSUES FACING PLATFORMS PARTICIPANTS & REGULATORS 6 (2015), https://www.ftc.gov/system/files/documents/reports/sharing-economy-issues-facing-platforms-participants-regulators-federal-trade-commission-staff/p151200_ftc_staff_report_on_the_sharing_economy.pdf [https://perma.cc/HNV5-K36M].

393. JOHAL & ZON, *supra* note 82, at 20.

394. *Airbnb and Your Neighborhood*, AIRBNB, https://www.airbnb.com/neighbors [https://perma.cc/TW2D-V8WV].

395. *See* Eric Goldman, *Regulating Reputation*, *in* THE REPUTATION SOCIETY: HOW ONLINE OPINIONS ARE RESHAPING THE OFFLINE WORLD 51, 53 (Hassan Masum & Mark Tovey eds., 2012).

396. Lobel, *supra* note 65, at 153.

397. FED. TRADE COMM'N, *supra* note 392, at 5–6; *see* Kendall L. Short, *Buy My Vote: Online Reviews for Sale*, 15 VAND. J. ENT. & TECH. L. 441, 443–44 (2013); *see also* Cannon & Chung, *supra* note 237, at 38–40. Some studies have found, for example, evidence of racial discrimination in ratings and rental practices on Airbnb. *See* BALARAM, *supra* note 64, at 45–46 (discussing studies finding that minorities are less likely to be accepted as

Notwithstanding their power and their central role in the sharing economy, platform companies cannot be expected to perform all desired governance functions. Platforms are ultimately private economic entities that may not adequately consider the interests of the public or of other stakeholders.[398] In some contexts, other nongovernmental entities—such as homeowners associations in the instance of short-term rentals, or associations of drivers in the case of Uber—may step in to represent other interests.[399]

Governance through platform companies may lack transparency, whether such governance involves government regulation or self-regulation.[400] In either case, the precise nature of a regulation, as well its source, may be obscured from users and the public. Users may not even be aware that their behavior is being regulated thanks to the subtlety with which a platform's software operates—whether in the form of matching algorithms, filters, or other features.[401] Lack of accountability is also a concern, as governance by platform companies may not allow for public participation or user input, and their decisions are not subject to democratic processes or judicial review.[402]

3. Self-Regulation

Online reputation systems, though usually mediated by platform companies, rely on the input of platform users.[403] These systems thus constitute a form of self-regulation, particularly when platforms make users' feedback directly available to other users and potential users. Users' cumulative feedback—and even the potential to receive a

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guests and are also less likely to earn the same income as an Airbnb host compared to a white person).

398. *See* Cohen & Sundararajan, *supra* note 261, at 131; *see also* Zale, *supra* note 74, at 1008–10 (noting resistance of some platform companies to participating in co-regulation).

399. *See* Cohen & Sundararajan, *supra* note 261, at 130–31 (arguing that homeowners associations are well suited to "play a key role in the regulation of local externalities" that Airbnb creates); Davey Alba, *NYC Uber Drivers Are Organizing—Just Don't Call It a Union*, WIRED (May 10, 2016), http://www.wired.com/2016/05/nyc-uber-drivers-organizing-just-dont-call-union/ [https://perma.cc/67UA-2XZR].

400. *Cf.* Lessig, *supra* note 219, at 541 (explaining that the law's regulation of code undermines transparency by enabling government regulation without revealing the government's role).

401. *See* Jack M. Balkin, *Information Power: The Information Society from an Antihumanist Perspective*, *in* THE GLOBAL FLOW OF INFORMATION: LEGAL, SOCIAL, AND CULTURAL PERSPECTIVES 232, 238–40 (Ramesh Subramanian & Eddan Katz eds., 2016); Lessig, *supra* note 219, at 509 ("The code, or the software and hardware that make cyberspace the way it is, constitutes a set of constraints on how one can behave.").

402. *See* Cohen & Sundararajan, *supra* note 261, at 131; Zale, *supra* note 74, at 998.

403. Goldman, *supra* note 395, at 52 (distinguishing unmediated and mediated reputation systems and providing examples of mediated systems).

negative review—can serve as incentives for good behavior, particularly with respect to repeat players.[404]

Indeed, the ongoing development of decentralized online marketplaces offers the prospect of peer-to-peer transactions occurring without a digital platform company serving as an intermediary.[405] These marketplaces are built upon blockchain technology, which relies on "a shared, trusted, public ledger that everyone can inspect, but which no single user controls" to keep track of transactions without a central oversight institution.[406] A sharing economy without middlemen would lack one of the more effective levers for government oversight and raise new challenges for governance.[407] Such a system would have a self-regulatory aspect in that users and coders would set the rules and help ensure the integrity of transactions.[408] It is not clear, however, that broader societal interests would be protected.[409] Government involvement in creating the computer code that underlies decentralized online marketplaces could provide a means of exerting influence and protecting the public interest.[410]

The sharing economy is already witnessing a combination of governance approaches that incorporate Big Data/Big Government, nongovernmental intermediaries, and self-regulation. Current approaches must continue to evolve in order to keep up with new developments and concerns.

404. *See* Koopman et al., *supra* note 71, at 541–43.

405. *See* BALARAM, *supra* note 64, at 29, 37–38 (discussing the growing number of co-operatives using blockchain technology to create "genuinely peer-to-peer market[s]").

406. *The Trust Machine: The Promise of the Blockchain*, ECONOMIST (Oct. 31, 2015), https://www.economist.com/news/leaders/21677198-technology-behind-bitcoin-could-transform-how-economy-works-trust-machine [https://perma.cc/T8FA-3MVR (dark archive)].

407. *See, e.g.*, BALARAM, *supra* note 64, at 29–30; U.K. GOV'T OFFICE FOR SCI., DISTRIBUTED LEDGER TECHNOLOGY: BEYOND BLOCK CHAIN 44 (2015), https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/492972/gs-16-1-distributed-ledger-technology.pdf [https://perma.cc/8Z4G-UKDH] (noting that attempts to regulate Bitcoin have focused on regulating businesses that deal with Bitcoin rather than Bitcoin itself because "no single entity is in control of the system").

408. *See, e.g.*, U.K. GOV'T OFFICE FOR SCI., *supra* note 407, at 43 (explaining that Bitcoin software can be changed only by core developers, who are "constrained by an informal self-imposed charter" requiring "broad consensus" for significant changes, and only if changes are adopted by a majority of Bitcoin miners).

409. *Cf.* BALARAM, *supra* note 64, at 38 (suggesting "shared regulation" by "a more comprehensive range of stakeholders").

410. *See* U.K. GOV'T OFFICE FOR SCI., *supra* note 407, at 44–45.

CONCLUSION

Characterized by new activities occurring outside established organizational arrangements, distributed innovation challenges traditional structures of management and authority. Distributed innovation fits poorly within existing legal categories, avoids ready detection, and metamorphoses into new forms. Experience in governing the conduct of individuals and small pollution sources, however, suggests possible means to influence distributed innovation in pursuit of public goals. Recognizing the challenge as one of governance, and not simply regulation, enables the recruitment of businesses, nonprofit organizations, and innovators themselves for managing the risks.

Given the various forms and contexts in which distributed innovation arises, there is no one-size-fits-all solution to the challenges it presents. Nor is any single governance tool likely to suffice within a particular context. The Big Data/Big Government approach is a tempting response to fears of catastrophic harm or misuse. Yet it cannot eliminate all risk, and it often comes at a high cost to the public fisc and to autonomy and privacy interests. Nongovernmental intermediaries can be an effective locus for government regulation, and in some instances they may develop their own measures to govern distributed innovators directly. Yet intermediaries may fail to account for relevant public concerns, and the legitimacy of their actions are open to question. Self-regulation offers a promising response to the practical difficulties distributed innovation poses for conventional regulation. At the same time, private interests are especially likely to predominate, and lack of legitimacy is of particular concern. Each of these approaches, however imperfect, may provide a valuable contribution to managing the risks of distributed innovation when used in concert with the others. Because distributed innovation takes different forms and is constantly adapting, the approaches utilized in its governance must also be flexible and adaptive. Governance of distributed innovation, it turns out, must be both distributed and innovative.