Harvard Journal of Law & Technology
Volume 35, Number 1 Fall 2021

PATENT LAW AND CLIMATE CHANGE: INNOVATION POLICY FOR A CLIMATE IN CRISIS

*Caoimhe Ring**

TABLE OF CONTENTS

I. INTRODUCTION

Meeting the Paris Agreement target of maintaining global average temperature increases "well below 2.0°C" and "pursuing efforts to limit the temperature increase to 1.5°C"[1] requires rapid innovation[2] in

---

* University of Oxford, DPhil Candidate in Intellectual Property Law. Email: caoimhe.ring@law.ox.ac.uk. With particular thanks to Professors Robert Burrell and Daniel Benoliel at the University of Oxford for their helpful comments and conversations, as well as valuable feedback from Professors David Campbell at Lancaster University and Bettina Lange at the University of Oxford. My deepest gratitude to Dr. Emily Hudson at King's College London for helpful feedback on the early stages of this project and continued encouragement to pursue this research. With thanks to Rowan Wilson for their patience.

1. Paris Agreement Under the United Nations Framework Convention on Climate Change art. 2(1)(a), *opened for signature* Dec. 12, 2015, T.I.A.S. No. 16-1104 (entered into force Nov. 4, 2016, rejoined by the U.S. Feb. 19, 2021) [hereinafter *Paris Agreement*].

2. *See* JOSEPH A. SCHUMPETER, THE THEORY OF ECONOMIC DEVELOPMENT: AN INQUIRY INTO PROFITS, CAPITAL, CREDIT, INTEREST, AND THE BUSINESS CYCLE 55–57 (Redvers Opie trans., Transaction Publishers 1983) (1911) (defining innovation as the "carrying out of new combinations," which covers five cases of economic activity, such as the introduction of a new good to the market).

climate-friendly, or green, technologies.[3] It is now unequivocal that human influences are changing the climate: there are now observed changes to weather extremes in every region of the globe, and some of these changes will be irreversible.[4] Technological solutions are needed to reduce greenhouse gas ("GHG") emissions in what may call for a "climate-technology revolution"[5] or a "Manhattan Project" for climate change that would rapidly develop new green technologies.[6] This could be the most formidable challenge for innovation policy in the twenty-first century.[7] The last-minute decision to water down commitments on phasing out coal at the 26th United Nations Climate Change Conference of the Parties only serves to highlight that emissions will be stabilized by novel technologies, not by putting an end to fossil fuels.[8] It signals to the prioritization of technological means to solve what is essentially a social problem: the need to lower GHG emissions. But there is much uncertainty about the feasibility of delivering the technological advances needed.[9] One open question for legal scholars is the role that patent law will play in the race for green innovation.

A substantial literature has mapped the relationship between patent law and green innovation. Innovation, in common use, typically refers to the entire innovative process. However, there is an important

---

3. U.N. Conference on Environment & Development Rio de Janeiro, Brazil, 3 to 14 June 1992, *Agenda 21*, Chapter 34.2, U.N. Doc [ST/]DPI/1344 (1993) (defining "environmentally sound technology" as technological solutions that generate low or no waste, for the prevention of pollution).

4. *See* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE [IPCC], CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS 5–12 (2021); IPCC, GLOBAL WARMING OF 1.5°C 8–9 (Valérie Masson-Delmotte et al. eds. 2018) https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf [https://perma.cc/UN3A-BZFF].

5. Scott Barrett, *The Coming Global Climate–Technology Revolution*, 23 J. ECON. PERSPS. 53, 53–54 (2009).

6. Richard R. Nelson, *The Moon and the Ghetto Revisited*, 38 SCI. & PUB. POL'Y 681, 688–89 (2011); *see also* INT'L ENERGY AGENCY [IEA], NET ZERO BY 2050: A ROADMAP FOR THE GLOBAL ENERGY SECTOR 3 (4th rev. 2021), https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf [https://perma.cc/BUC9-EMCB] (noting that reaching net-zero emissions by 2050 will require a major acceleration in green energy innovation).

7. U.N. Secretary-General, Secretary-General's Remarks on Climate Change [as delivered] (Sept. 10, 2018), https://www.un.org/sg/en/content/sg/statement/2018-09-10/secretary-generals-remarks-climate-change-delivered [https://perma.cc/WC45-5P4X] (declaring climate change as "the defining issue of our time").

8. *See generally As It Happened: Climate Deal Agreed with Last-Minute Change on Coal*, BBC, (Nov. 13, 2021), https://www.bbc.co.uk/news/live/uk-59253838 [https://perma.cc/K2MN-MTVG].

9. *See* Adam B. Jaffe, Richard G. Newell & Robert N. Stavins, *A Tale of Two Market Failures: Technology and Environmental Policy*, 54 ECOLOGICAL ECON. 164, 164–65 (2005); Peter J. Loftus, Armond M. Cohen, Jane C.S. Long & Jesse D. Jenkins, *A Critical Review of Global Decarbonization Scenarios: What Do They Tell Us About Feasibility?*, 6 WIREs CLIMATE CHANGE 93, 106–07 (2015) (explaining that most decarbonization scenario modelling omits detailed examination of technological readiness).

distinction between invention as a pre-market activity and innovation that refers to technology commercialization and diffusion in the marketplace.[10] Scholarly opinion is divided on how the patent system should adapt to the challenge of climate change. This Note loosely divides the literature into two camps: one characterized by skepticism and one by pragmatism.[11] Drawing on Ofer Tur-Sinai's "[s]keptic's view," the suggestion amongst patent skeptics is that patents may under-provide for, or even stymie, green innovation.[12] Even the pragmatic view, which emphasizes patent law's potential for positive impact on green innovation, acknowledges that significant patent law reform would be required.[13] When it comes to choosing between the models for patent law reform, however, it becomes clear that less is written on the specific problem the patent system confronts. What are the challenges ahead for green innovation policy, and what are its implications for patent law? To answer this question, this Note proffers a fresh perspective on the factors that promote and constrain green energy innovation.[14] Importantly, while access to technology is undoubtedly worthy of attention, this Note focuses principally on the incentive effects of patent law on green technological advance.

This Note suggests patents may be less significant for promoting green *invention* at early research stages but still imperative for green *innovation* — encouraging commercialization and diffusion in mature energy technology markets. Part II describes stylized facts[15] about

10. CHRISTINE GREENHALGH & MARK ROGERS, INNOVATION, INTELLECTUAL PROPERTY AND ECONOMIC GROWTH 4–6 (2010).

11. Of course, this characterization is the author's own and is somewhat reductive, though it is fair to suggest the literature is divided by presuppositions about whether the patent system can be improved or is simply an inadequate tool when it comes to climate-friendly innovation. One implication of this divide is that patent skeptics are willing to look beyond patents to prize or reward systems, whilst the pragmatic view seems to acknowledge that patent rights are here to stay, and thus, patent rules need revision to ensure they positively impact green innovation. *See infra* Part III.

12. *See, e.g.*, Ofer Tur-Sinai, *Patents and Climate Change: A Skeptic's View*, 48 ENV'T L. 211, 213–17 (2018) (expressing skepticism that a status quo patent system will encourage green innovation). Peter Drahos has concisely and forcefully argued why the international intellectual property system is unlikely to ameliorate our current state of climate emergency. *See* Peter Drahos, *Six Minutes to Midnight: Can Intellectual Property Save the World?*, *in* EMERGING CHALLENGES IN INTELLECTUAL PROPERTY 30, 42–45 (Kathy Bowrey et al. eds., 2011) ("A single sentence conclusion would be that the patent institution will do little to drive the big science that is needed, especially in the energy sector, to avoid the worst climate change scenarios.").

13. *See generally* ABBE E.L. BROWN, INTELLECTUAL PROPERTY, CLIMATE CHANGE AND TECHNOLOGY: MANAGING NATIONAL LEGAL INTERSECTIONS, RELATIONSHIPS AND CONFLICTS (2019); Estelle Derclaye, *Intellectual Property Rights and Global Warming*, 12 MARQ. INTELL. PROP. L. REV. 263 (2008).

14. *See infra* Part II.

15. *See* Nicholas Kaldor, *Capital Accumulation and Economic Growth*, *in* THE THEORY OF CAPITAL 177, 178 (D.C. Hague ed., 1961) (explaining the utility of stylized facts in theorizing as propositions which express the broad tendencies that emerge from empirical findings, though which may not hold in all settings).

green energy innovation to contextualize the policy issues beyond patent law. Part III analyzes the literature on patent law reform in response to climate change, suggesting that it disregards important aspects of the green innovation policy challenge for patent law: notably, it devotes little attention to market uptake of mature energy technologies. The main contribution of this Note, in Part IV, is the argument that patents may have a thus far under-examined role in promoting green *innovation* — commercialization and diffusion. While several scholars have made valuable contributions, there is insufficient examination of patentee practice from a theoretical or empirical standpoint. This is problematic as a matter of present knowledge, but also poses the risk of neglecting a key component of the patent system as it affects green innovation. It is suggested that commercialization and diffusion have escaped attention by virtue of failure to take stock of the broader innovation context. To remedy these issues, this Note touches on the benefits of an interdisciplinary approach to isolate which policy issues are best dealt with in patent law. It briefly comments on use of the innovation system as a framing device system to determine when patents are more appropriate as compared to alternative measures, such as prize or grant systems. Part V concludes with broader theoretical implications for patent law and policy.

II. Green Energy Innovation

A. Technological Solutions for Energy Decarbonization

The Paris Agreement targets have the effect of emphasizing the role that technology plays in reducing GHG emissions. The targets are to reduce GHG emissions, particularly cumulative net carbon-dioxide ("CO2") emissions.[16] Reducing cumulative emissions requires both emissions stabilization *and* removal of existing atmospheric CO2 — a metric which places substantial reliance on new carbon-dioxide removal technologies ("CDRs") to counteract residual emissions that are not reduced by, for instance, switching to renewable energy sources.[17] Under that metric, a 1.5°C target requires CO2 emissions to

16. *See* Paris Agreement, *supra* note 1, at art. 4; *see generally* Myles R. Allen et al., *Warming Caused by Cumulative Carbon Emissions Towards the Trillionth Tonne*, 458 NATURE 1163, 1163 (2009) (explaining how the metric of cumulative emissions describes existing stocks of CO2 emissions, roughly half of which have been emitted since industrialization began).

17. Examples of CDR technologies include direct air capture or carbon-capture-and-storage technologies. H. Damon Matthews & Ken Caldeira, *Stabilizing Climate Requires Near-Zero Emissions*, GEOPHYSICAL RSCH. LETTERS, Feb. 27, 2008, at 1, 1, 4–5; EUR. ACADEMIES' SCI. ADVISORY COUNCIL [EASAC], NEGATIVE EMISSION TECHNOLOGIES: WHAT ROLE IN MEETING PARIS AGREEMENT TARGETS? 5 (2018), https://easac.eu/fileadmin/PDF_s/reports_statements/Negative_Carbon/EASAC_Report_on_Negative_Emission_Technologies.pdf [https://perma.cc/CK3L-2G57]

decrease to near or net-zero by the second half of this century.[18] The Paris Agreement targets thus give prominence to CDR technologies, many of which are still in early development.[19]

At the same time, technology is no silver bullet. There is no fix-all for climate change, or the many changes it necessitates — for instance, to agriculture, patterns of consumption, and waste management.[20] However, green energy technologies can have determinative impacts on meeting the time-limited Paris Agreement targets.[21] On the other hand, overconfident technology forecasting poses risks. For instance, though carbon-capture-and-storage ("CCS") is projected to be an especially impactful technology, estimates on its potential emissions abatement are highly uncertain.[22] In some cases, however, the

---

(explaining that imminent action is needed to reduce cumulative CO2 emissions in part due to CO2's long atmospheric residence time, which means that current CO2 stocks will increase heat absorption for hundreds of years).

18. IPCC, GLOBAL WARMING OF 1.5˚C, *supra* note 4, at 468.

19. Kevin Anderson, *Duality in Climate Science*, 8 NATURE GEOSCIENCE 898, 899 (2015).

20. *See* Klaus Rennings, *Redefining Innovation — Eco-Innovation Research and the Contribution from Ecological Economics*, 32 ECOLOGICAL ECON. 319, 321–24 (2000) (arguing that "eco-innovation" ought to be defined to avoid a technological bias, and should include social and organizational change, such as "eco-audits" of firms). Technology plays an ambiguous and contested role in climate stabilization projections. Though the majority of decarbonization scenarios consistent with the Paris Agreement's objectives would require vast and sustained use of CO2 removal technologies, there are many uncertainties about its technical or economic feasibility. *See, e.g.*, J.M. ALLWOOD ET AL., ABSOLUTE ZERO: DELIVERING THE UK'S CLIMATE CHANGE COMMITMENT WITH INCREMENTAL CHANGES TO TODAY'S TECHNOLOGIES 1–3 (2019), http://www.ukfires.org/wp-content/uploads/2019/11/Absolute-Zero-online.pdf [https://perma.cc/LR7L-XTEV] (starting from the premise that "although some exciting new technology options are being developed, it will take a long time to deploy them, and they won't be operating at scale within thirty years" to meet net-zero targets, but that there are many behavioral changes that can be made today to reduce GHG emissions, such as reducing one's consumption of beef and lamb); Pete Smith et al., *Biophysical and Economic Limits to Negative CO2 Emissions*, 6 NATURE CLIMATE CHANGE 42, 48–49 (2016) (estimating the biophysical and economic resource costs associated with deployment of CDR technologies consistent with the Paris agreement carbon budgets, revealing the strain it could place on sustainable development goals, such as food, water, and energy security); Glen P. Peters, *The 'Best Available Science' to Inform 1.5 °C Policy Choices*, 6 NATURE CLIMATE CHANGE 646, 647 (2016) (explaining that while nearly all models which predict pathways to staying well below 2˚C use CO2 removal, there is considerable uncertainty over the feasibility of various CO2 removal techniques); Detlef P. van Vuuren, Andries F. Hof, Mariësse A.E. van Sluisveld & Keywan Riahi, *Open Discussion of Negative Emissions Is Urgently Needed*, 2 NATURE ENERGY 902, 902–04 (2017) (arguing that lack of support and investment in CO2 removal threatens our ability to meet climate targets, and stands in contrast to the stated need for these technologies in most climate change modelling).

21. BP, ENERGY OUTLOOK: 2020 EDITION 21 (2020) https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2020.pdf [https://perma.cc/5QEH-SKRX] (explaining that energy use accounts for roughly 65% of GHG emissions globally).

22. Note, for instance, that while one group of leading scientists advocate mass rollout of negative emissions technology — which includes CCS technology — another prescribes it a much more limited role. *Compare* EASAC, *supra* note 17, at 11–14 (arguing that carbon removal technologies may have significant effects on climate stabilization in the long run,

only solutions to meeting net-zero energy demand are technological.[23] What makes technological solutions attractive is that they can reduce the costs of CO2 emissions reductions.[24] Even if all current unconditional emissions pledges are met, a minimum 2.7°C temperature rise is forecasted by 2100.[25] Global economic damages resulting from a 1.5°C increase alone may cost up to 54 trillion USD.[26] Technologies provide new, cheaper means of achieving climate goals to avert political stalemates if costs prove too high.[27] Of course, green technology characteristics vary tremendously, even within the renewable energy industry. The actual implementation of energy inventions is affected by several factors including, *inter alia*, national energy grid characteristics which vary considerably by country.[28] In practice, the relevant costs and benefits of a particular solution will vary significantly.[29]

---

but that these technologies are too novel to be considered a credible option in the short term), *with* Mai Bui et al., *Carbon Capture and Storage (CCS): The Way Forward*, 11 ENERGY & ENV'T SCI. 1062, 1145 (2018) (contending that "CCS is not just vital to the cost-optimal solution, it is vital to the solution, period" after a comprehensive review of available techniques and areas which require future research and development).

23. Importantly, CDR could be very impactful for what are called hard-to-abate industries, for which decarbonization is a more difficult and protracted process. *See, e.g.*, IEA, *supra* note 6, at 126–27 (explaining the use of CDR in energy-intensive activities, such as steel production).

24. Nicholas Stern's economic approach to quantifying the risks of climate change has been especially impactful for policymakers. *See* NICHOLAS STERN, THE ECONOMICS OF CLIMATE CHANGE: THE STERN REVIEW 241 (2007). However, cost-benefit analysis of this sort has been criticized for failure to properly account for the social impacts of climate change. *See, e.g.*, Rob White, *Technology, Environmental Harm and Green Criminology*, *in* THE ROUTLEDGE HANDBOOK OF TECHNOLOGY, CRIME AND JUSTICE 241, 248–52 (M.R. McGuire & Thomas J. Holt eds., 2017) (examining how demand for biofuels increases food prices for impoverished communities, and is linked to the destruction of unique, local plant genotypes through the invasion of genetically modified crops used for biofuel production).

25. U.N. ENV'T PROGRAMME [UNEP], EMISSIONS GAP REP. 2021 12 (2021) https://wedocs.unep.org/bitstream/handle/20.500.11822/36991/EGR21_ESEN.pdf [https://perma.cc/44EL-SFX4]; *see also* Dan Tong et al., *Committed Emissions from Existing Energy Infrastructure Jeopardize 1.5°C Climate Target*, 572 NATURE 373, 375–76 (2019) (estimating that commitments to existing plans to increase energy infrastructure projects will overshoot the CO2 budgets consistent with a 1.5°C target).

26. IPCC, GLOBAL WARMING OF 1.5°C, *supra* note 4, at 264.

27. Nelson, *supra* note 6, at 689; *see generally* Jae Edmonds, John Clarke, James Dooley, Son H. Kim & Steven J. Smith, *Stabilization of CO2 in a B2 World: Insights on the Roles of Carbon Capture and Disposal, Hydrogen, and Transportation Technologies*, 26 ENERGY ECON. 517, 535 (2004) (finding, under certain conditions, that advanced technologies such as hydrogen power could halve the costs of emissions abatement in their global market equilibrium model).

28. *See, e.g.*, Joy Y. Xiang, *IPR Management in International Cleantech Cooperation*, 32 GEO. ENV'T L. REV. 1, 11–13 (2019) (explaining that green technologies cover many heterogeneous technologies and industries, varying by geography and deriving from considerations such as differing national energy grid infrastructure).

29. While new energy sources such as hydrogen energy may be considered an innovation of the chemistry industry, energy use may encompass many more industries. Smart grids, for instance, will involve components emerging from semiconductor innovation, which has very different patterns of innovation.

The grave reality of climate change, however, means innovation is needed for novel and mature technologies.[30] For instance, in the next fifty years, if current trends continue, the proportion of renewable energy sources could rise to 60% globally.[31] Mature green technologies, or those which are at least at the early adoption stage, will make a substantial contribution to reaching net-zero targets.[32] Yet policymakers increasingly rely on novel solutions, many of which, such as CDR, are not ready for commercial deployment.[33] Rollout of renewable energy, however, hinges crucially on consumer behavior and market uptake of existing solutions at the commercialization and diffusion stages of innovation.[34] There are open questions about patents for technology commercialization and diffusion.[35]

---

30. *See* ALLWOOD ET AL., *supra* note 20, at 1 (arguing that the net-zero by 2050 target in the United Kingdom can be achieved by cutting energy use to 60% of today's levels using only incremental improvements to today's technologies, and a number of behavioral changes); IEA, ENERGY TECHNOLOGY PERSPECTIVES 2020 327–32 (2020), https://iea.blob.core.windows.net/assets/7f8aed40-89af-4348-be19-c8a67df0b9ea/Energy_Technology_Perspectives_2020_PDF.pdf [https://perma.cc/3DXU-3LG3] (projecting that almost half of emissions reductions by 2070 rely on technologies still at the large prototype or demonstration stages of innovation); Jan C. Minx et al., *Negative Emissions — Part 1: Research Landscape and Synthesis*, ENV'T RSCH. LETTERS, May 22, 2018, at 1, 13 (explaining that climate stabilization projections are reliant on the availability of multiple forms of CDR).

31. IEA, *supra* note 30, at 80–81.

32. *Id.* at 327–32.

33. ALLWOOD ET AL., *supra* note 20, at 9–10 (noting that while an "invisible, technology-led, solution to climate change is . . . attractive," expecting that the brunt of the problem can be solved by future breakthroughs is not a strategy without risks); *see also* EASAC, *supra* note 17, at 10; Anderson, *supra* note 19, at 899 (explaining that 344 out of 400 modelling scenarios behind the 2018 IPCC report rely on the deployment of CDRs to have an even 50% chance of staying within a 2°C temperature rise). The rhetoric on the transformative potential of novel technologies marginalizes the voices of those *without the capacity to wait* — those from threatened small island nations or at climate extremes. At the very least, an uncritical acceptance that CDR is the only tenable option to lower GHG emissions insulates from political contestation the role of civil society in overcoming climate disaster. For intellectual property law, however, the next sections reveal patents that are unlikely to incentivize green energy breakthroughs in any case.

34. Bearing in mind that, despite short timeframes ahead to reduce GHG emissions, even the commercialization alone can take decades. *See generally* Robert Gross, Richard Hanna, Ajay Gambhir, Philip Heptonstall & Jamie Speirs, *How Long Does Innovation and Commercialisation in the Energy Sectors Take? Historical Case Studies of the Timescale from Invention to Widespread Commercialisation in Energy Supply and End Use Technology*, 123 ENERGY POL'Y 682 (2018) (reviewing historical evidence to find that energy technology maturity varies tremendously, with commercialization taking between twenty to seventy years and with many solutions taking thirty to forty years to reach the market).

35. Several large-scale patent surveys establish that patents enable firms to commercialize inventions. *See generally, e.g.*, Richard C. Levin, Alvin K. Kelvorick, Richard R. Nelson, Sidney G. Winter, Richard Gilbert & Zvi Griliches, *Appropriating the Returns from Industrial Research and Development*, 1987 BROOKINGS PAPERS ON ECON. ACTIVITY 783 (1987); Wesley M. Cohen, Richard R. Nelson & John P. Walsh, *Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not)* 1 (Nat'l Bureau of Econ. Rsch., Working Paper No. 7552, 2000), https://www.nber.org/system/files/working_papers/w7552/w7552.pdf [https://perma.cc/G9WR-PDKM]; Clarisa Long, *Patent Signals*, 69 U. CHI. L. REV. 625

B. Basic Science

Because early developments in green innovation are driven by basic scientific research, patents are generally thought to be unsuitable incentive mechanisms for this blue skies research.[36] Firms underinvest in basic scientific research due to inability to shift risk, moral hazard, and low expected returns.[37] These capital-intensive, risky projects are rife with knowledge spillovers, meaning that their returns are not fully appropriable.[38] As research projects concerning fundamental ideas of science, these spillovers reach multiple industries, carrying on downstream.[39] With uncertainty comes long time periods to arrive at solutions.[40] And as technologies mature, incremental advances take longer.[41]Yet much investment in green innovation is still led by the public sector.[42] In 2019, approximately 80% of the public energy research and development ("R&D") budget of 30 billion USD was devoted to green energy, while the *total* private sector energy R&D budget was 9 billion USD — a sum that includes environmentally-

(2002); Stuart J.H. Graham, Robert P. Merges, Pam Samuelson & Ted Sichelman, *High Technology Entrepreneurs and the Patent System: Results of the 2008 Berkeley Patent Survey*, 24 BERKELEY TECH. L.J. 1255 (2009); Amelia S. Rinehart, *Patents as Escalators*, 14 VAND. J. ENT. & TECH. L. 81 (2011); Stuart J.H. Graham & Ted Sichelman, *Why Do Start-Ups Patent?*, 23 BERKELEY TECH. L.J. 1063 (2008). For further discussion on this point *see infra* Part IV.

36. *See* Kelly Sims Gallagher, John P. Holdren & Ambuj D. Sagar, *Energy Technology Innovation*, 31 ANN. REV. ENV'T & RES. 193, 202 (2006) (explaining that the research areas most relevant to energy innovation are typically materials science, combustion, fusion, or energy biosciences research).

37. *See* Richard R. Nelson, *The Simple Economics of Basic Scientific Research*, 67 J. POL. ECON. 297, 300–04 (1959); Kenneth J. Arrow, *Economic Welfare and the Allocation of Resources for Invention*, *in* THE RATE AND DIRECTION OF INVENTIVE ACTIVITY: ECONOMIC AND SOCIAL FACTORS 609, 614–19 (Nat'l Bureau of Econ. Rsch. ed., 1962).

38. David C. Mowery, Richard R. Nelson & Ben R. Martin, *Technology Policy and Global Warming: Why New Policy Models are Needed (or Why Putting New Wine in Old Bottles Won't Work*), 39 RSCH. POL'Y 1011, 1013 (2010).

39. *See generally* Robert P. Merges & Richard R. Nelson, *On the Complex Economics of Patent Scope*, 90 COLUM. L. REV. 839 (1990).

40. IEA, *supra* note 6, at 76; Gross et al., *supra* note 34, at 684.

41. Robert K. Perrons, Adam B. Jaffe & Trinh Le, *Tracing the Linkages Between Scientific Research and Energy Innovations: A Comparison of Clean and Dirty Technologies* 4 (Nat'l Bureau of Econ. Rsch., Working Paper No. 27777, 2020) (estimating that the time taken for scientific findings to be incorporated into green energy patents has risen from five to eight years since the 1980s).

42. *See* STERN, *supra* note 24, at 412–15; IEA, *supra* note 30, at 317–22; Gallagher et al., *supra* note 36, at 202; *e.g.*, Goksin Kavlak, James McNerney & Jessika E. Trancik, *Evaluating the Causes of Cost Reduction in Photovoltaic Modules*, 123 ENERGY POL'Y 700, 707 (2018) (explaining that solar power reached an economy of scale through government subsidization, with dramatic drops in production costs thereafter); *see also* L. Fleming, H. Greene, G. Li, M. Marx & D. Yao, *Government-Funded Research Increasingly Fuels Innovation*, 364 SCIENCE 1139, 1141 (2019) (suggesting that the productivity of corporate research increasingly relies on ideas arising from publicly funded R&D).

damaging energy projects.[43] Public financing commitments will often impose obligations to encourage private investment.[44] At this later stage of innovation, patents are paradigmatically significant, once R&D culminates into marketable goods or services.[45]

C. The Pollution Problem

Relatedly, private actors are disincentivized to invest in green R&D without a socially optimal price on carbon. Termed the "double externality problem" ("DEP"), green innovation faces a double market failure that creates a rift between its social value and private return.[46] The positive externalities associated with innovation combine with the negative externalities of environmental harm. Polluters impose third-party costs while the market price of pollution is well below its social cost.[47] Profit-maximizing firms engage in more environmentally harmful activity than is socially optimal.[48] Correlatively, the social benefits of green technology are underpriced. Thus, green innovation is doubly underpriced even in the presence of the patent reward.[49] Green technology's social value well exceeds the private return *and* social value of technologies without a double externality.[50] This diminishes incentives to invest in green technology. Patents do little to

---

43. IEA, *supra* note 30, at 318–19. *But see* Arnulf Grubler et al., *Policies for the Energy Technology Innovation System (ETIS)*, *in* GLOBAL ENERGY ASSESSMENT: TOWARD A SUSTAINABLE FUTURE, 1665, 1713 (Thomas B. Johansson et al. eds., 2012) (suggesting that because the IEA only reports on its thirty member countries, its public-sector energy research, development, and demonstration ("RD&D") statistics may cover only a quarter of all energy-related RD&D globally).

44. *See, e.g.*, T.J. Foxon, R. Gross, A. Chase, J. Howes, A. Arnall & D. Anderson, *UK Innovation Systems for New and Renewable Energy Technologies: Drivers, Barriers and Systems Failures*, 33 ENERGY POL'Y 2123, 2127–28 (2008) (explaining that the United Kingdom's Renewables Obligation introduced in 2002 provides grants to early-stage technologies, requiring electricity providers to increase their renewable energy sources annually or pay for non-compliance).

45. *See infra* Part IV.

46. *See, e.g.*, William Nordhaus, *Designing a Friendly Space for Technological Change to Slow Global Warming*, 33 ENERGY ECON. 665, 666–67 (2011); Bronwyn H. Hall & Christian Helmers, *The Role of Patent Protection in (Clean/Green) Technology Transfer*, 26 SANTA CLARA HIGH TECH. L.J. 487, 488–91 (2009); *see also* Jaffe et al., *supra* note 9, at 165.

47. *See* Nordhaus, *supra* note 46, at 666; *see generally* NATHANIEL O. KEOHANE & SHEILA M. OLMSTEAD, MARKETS AND THE ENVIRONMENT 80–98 (2d ed., 2016) (providing a comprehensive overview of how rational actors will use natural resources in a suboptimal manner due to the negative externalities associated with environmental damage).

48. *See* Natalie M. Derzko, *Using Intellectual Property Law and Regulatory Processes to Foster the Innovation and Diffusion of Environmental Technologies*, 20 HARV. ENV'T L. REV. 3, 20 (1996).

49. *See* Harold Demsetz, *Toward a Theory of Property Rights*, 57 AM. ECON. REV. 347, 359 (1967) (explaining that patents, as property rights, internalize some of the positive externalities associated with innovation).

50. Nordhaus, *supra* note 46, at 666–67.

alleviate the problem because many social benefits cannot be captured in monetary terms. Other benefits are not patentable.[51]

The DEP ultimately supports the proposition that without a global, optimal carbon tax, firm investment in green innovation will be suboptimal.[52] But the model omits the pressure points for innovation policy, such as what happens when spillovers are incorrectly priced, or what the implications are when factoring in known characteristics of green technologies, such as network effects.[53] The empirical evidence suggests that carbon taxes have little impact on green innovation.[54] Without a global carbon taxation regime in place, no optimal price presently exists.[55]

Similarly, environmental regulation's impact on innovation has fallen short of expectations. Early work by Michael Porter and Claas van der Linde hypothesized that environmental regulation could drive firm competition in "innovation offsets" that counterbalance the compliance costs imposed by regulation.[56] Regulation simultaneously signals the need for green solutions, reducing the uncertainty of green R&D, while encouraging firms to innovate to gain an early-mover advantage in complying with new regulations.[57] For instance, firms may innovate in new packaging solutions where regulation increases the costs of plastic packaging. There is evidence that regulatory increases to fuel prices increase green patenting.[58] But the effects ap-

51. *See* Zachary Liscow & Quentin Karpilow, *Innovation Snowballing and Climate Law*, 95 WASH. U. L. REV. 387, 398 (2017) (giving the example of learning-by-doing as a socially beneficial activity which cannot be patented).

52. For William Nordhaus, a cap-and-trade scheme or a carbon tax fully internalizes the pollution externality, such that — theoretically speaking — no further intervention is needed to encourage green innovation. Nordhaus, *supra* note 46, at 668–70 (explaining that it would put green innovation "on a level playing field with all other economic activity").

53. *Id.* at 670–71.

54. Johan Lilliestam, Anthony Patt & Germán Bersalli, *The Effect of Carbon Pricing on Technological Change for Full Energy Decarbonization: A Review of Empirical Ex-Post Evidence*, WIREs CLIMATE CHANGE, Jan.–Feb. 2021, at 1, 9, 17–18 (finding in their review of nineteen empirical, ex post analyses of carbon pricing schemes in the European Union, Nordic countries, and New Zealand that there was no evidence that carbon pricing schemes drive innovation).

55. This does not, however, preclude the possibility that optimal carbon pricing could drive green innovation. *See* William Nordhaus, *Climate Change: The Ultimate Challenge for Economics*, 109 AM. ECON. REV. 1991, 2003 (2019) (arguing that a carbon price will "give market incentives for inventors, innovators, and investment bankers to invent, fund, develop, and commercialize new low-carbon products and processes").

56. Michael E. Porter & Claas van der Linde, *Toward a New Conception of the Environment-Competitiveness Relationship*, J. ECON. PERSPS. 97, 99–105 (1995).

57. *Id.*

58. Philippe Aghion, Antoine Dechezleprêtre, David Hémous, Ralf Martin & John Van Reenen, *Carbon Taxes, Path Dependency, and Directed Technical Change: Evidence from the Auto Industry*, 124 J. POL. ECON. 1, 24–27 (2016) (finding in a panel regression on more than 25,000 auto-industry patent applications that higher fuel prices incentivized roughly 10% more clean patenting versus a 6% decrease in combustion-engine patenting in the same year).

pear rather industry-specific.[59] Moreover, identifying causal relationships between regulatory change and increased innovative activity is difficult. Much innovation cannot be explained by the models: the hypothesis is "either half-full or half-empty."[60] Increasingly, it is acknowledged that standalone environmental regulation drives little innovation.[61]

D. Short Timescales and Path Dependency

What makes climate change a "super wicked" problem, or an especially intractable problem, is that time is running out.[62] At the same time, energy innovation is subject to path-dependency, making rapid changes difficult. Path-dependency expresses how each innovator "stand[s] on the shoulders of giants."[63] It explains a range of phenomena, from how QWERTY keyboard key-ordering became "locked in" as a de facto industry standard since the early twentieth century, to how colonial-era railway tracks are deterministic of settlement patterns of major cities to date.[64] Each innovation amasses knowledge stocks in a given technological field, where the choices of early innovators disproportionately direct future innovators towards technologies with larger knowledge stocks and spillovers.[65] It prevails from the accumulation of "historical accidents," such that even remote

---

59. *Compare* Smita B. Brunnermeier & Mark A. Cohen, *Determinants of Environmental Innovation in US Manufacturing Industries*, 45 J. ENV'T ECON. & MGMT. 278, 290 (2003) (finding in a study on 146 manufacturing firms that increased costs of pollution abatement expenditure correlate with small but significant increases in green patenting) *with* Joëlle Noailly, *Improving the Energy Efficiency of Buildings: The Impact of Environmental Policy on Technological Innovation*, 34 ENERGY ECON. 795, 805 (2012) (finding that in building materials, regulatory standards have higher incentive effects than prices changes).

60. Richard Newell, Adam B. Jaffe & Robert N. Stavins, *The Induced Innovation Hypothesis and Energy-Saving Technological Change*, 114 Q.J. ECON. 941, 969–70 (1999).

61. Pablo del Río González, *The Empirical Analysis of the Determinants for Environmental Technological Change: A Research Agenda*, 68 ECOLOGICAL ECON. 861, 868 (2009); *see* Michael A. Gollin, *Using Intellectual Property to Improve Environmental Protection*, 4 HARV. J.L. & TECH. 193, 226–28 (1991) (criticizing environmental regulation for penalizing environmentally harmful technologies but not effectively promoting green technologies).

62. Kelly Levin, Benjamin Cashore, Steven Bernstein & Graeme Auld, *Overcoming the Tragedy of Super Wicked Problems: Constraining Our Future Selves to Ameliorate Global Climate Change*, 45 POL'Y SCIS. 123, 124, 127 (2012).

63. Suzanne Scotchmer, *Standing on the Shoulders of Giants: Cumulative Research and the Patent Law*, 5 J. ECON. PERSPS. 29, 29–30 (1991) (noting how each innovator builds on the progress of former innovators, such that optimal patent design seeks to divide up rewards between early and later innovators).

64. Paul David, *CLIO and the Economics of QWERTY*, 75 AM. ECON. REV. (PAPERS & PROC.) 332, 334 (1985); Remi Jedwab, Edward Kerby & Alexander Moradi, *History, Path Dependence and Development: Evidence from Colonial Railways, Settlers and Cities in Kenya*, 127 ECON. J. 1467, 1491 (2017).

65. *See* Daron Acemoglu, *Directed Technical Change*, 69 REV. ECON. STUD. 781, 793 (2002).

events can greatly impact eventual outcomes.[66] Natural resource abundance, imperfect substitutability between forms of energy, and great uncertainty over what energy sources will be successful in the long run means that, historically, energy transitions are slow.[67] Investments are typically large-scale and long-term, with high sunk costs, and energy providers generally compete on price, not on quality.[68] Switching costs can be so high as to require technology-specific market interventions to overcome this market failure.[69] But path-dependence is a double-edged sword: technology-specific government support can either have the desired snowball effect, or create the *wrong* path dependencies.[70] One objection to CCS, for example, is that it may perpetuate reliance on fossil-fuel energy sources.[71]

Path-dependency is reinforced by an amalgam of socio-economic forces that forestall energy decarbonization. Complementarities relating to existing energy infrastructure present barriers to entrepreneurs entering the market to offer new green technologies.[72] Network effects hinder the uptake of technologies that require infrastructure or changes to user habits. For example, the rollout of electric vehicles requires charging stations to be in place, though there is little incentive for private actors to implement stations without pre-existing demand for electric vehicles.[73] Infrastructure and supply chains are locked in as technologies mature. Oil energy infrastructure is so costly as to lock in future investments towards improvements and maintenance.[74] But these factors go beyond the firm level. A review of global, government fossil fuel subsidies over the 2010 to 2014 period was

66. David, *supra* note 64, at 335; *see* NATHAN ROSENBERG, EXPLORING THE BLACK BOX: TECHNOLOGY, ECONOMICS, AND HISTORY 9–23 (1994).

67. *See id.* at 183–89.

68. That energy providers compete on price only furthers the sense that carbon pricing forms a necessary part of any green innovation policy. *See* Karsten Neuhoff, *Large-Scale Deployment of Renewables for Electricity Generation*, 21 OXFORD REV. ECON. POL'Y 88, 98 (2005). For instance, the uptake of the steam engine in the United States was slow initially due to its natural resource abundance. Existing, less productive energy sources, such as wood energy, were thus retained because they were cheaper in the United States than in the resource-poor United Kingdom. *See* ROSENBERG, *supra* note 66, at 174–77.

69. *See* Paul Lehmann & Patrik Söderholm, *Can Technology-Specific Deployment Policies Be Cost-Effective? The Case of Renewable Energy Support Schemes*, 71 ENV'T & RES. ECON. 475, 487 (2018).

70. Philippe Aghion, Cameron Hepburn, Alexander Teytelboym & Dimitri Zenghelis, *Path Dependence, Innovation and the Economics of Climate Change*, *in* HANDBOOK ON GREEN GROWTH 78 (Richard Fouquet ed., 2019).

71. *Id.* at 79.

72. *See id.* at 70.

73. *See generally* William Sierzchula, Sjoerd Bakker, Kees Maat & Bert van Wee, *The Influence of Financial Incentives and Other Socio-Economic Factors on Electric Vehicle Adoption*, 68 ENERGY POL'Y 183 (2014).

74. *See* Liscow & Karpilow, *supra* note 51, at 447; Abbe E.L. Brown, *Lessons from Technology and Intellectual Property in the Oil and Gas Industry in Scotland: A Scholarly Journey and an Empirical Review*, 11 SCRIPTED 10, 23–24 (2014) (arguing that the revenue structure of the oil and gas industry is simply not suited to research and development).

valued from 160 to 200 billion USD.[75] Disagreement over metrics, however, means the range could be anywhere between 170 billion to 5.3 trillion USD annually.[76] These factors set our economy in a state of "carbon lock-in."[77] Carbon lock-in suggests that only strong, imminent action will be effective.

E. From Breakthroughs to Mature Energy Solutions

A comprehensive review of the dynamics of green energy innovation goes beyond this illustrative account, although it is fair to suggest that patents are an inappropriate tool for green *invention*, even if that does not rule out a role for patents later in the innovation process. In any case, history suggests that green innovation policy requires a portfolio of measures. Standalone policy measures, such as carbon taxes or other means of "getting the prices right," are insufficient.[78] Delays in implementing today's optimal decarbonization policy can lead to massive welfare losses if implemented later.[79] A portfolio of measures can offset the costs imposed by different policy levers.[80] Complementary policies are needed, including supply-push and demand-pull policy levers, balanced amongst technology-specific imperatives and open-ended regulatory standards.[81] Climate prizes, taxation, and regu-

---

75. ORG. FOR ECON. COOP. AND DEV. [OECD], OECD COMPANION TO THE INVENTORY OF SUPPORT MEASURES FOR FOSSIL FUELS 2015 42 (2015), https://www.oecd.org/environment/oecd-companion-to-the-inventory-of-support-measures-for-fossil-fuels-2015-9789264239616-en.htm [https://perma.cc/SC7D-UT4C].

76. Doug Koplow, *Defining and Measuring Fossil Fuel Subsidies*, *in* THE POLITICS OF FOSSIL FUEL SUBSIDIES AND THEIR REFORM 23, 32 (Jakob Skovgaard & Harro van Asselt eds., 2018) (findings based on 2015 data); *see also* David Coady, Ian Parry, Nghia-Piotr Le & Baoping Shang, *Global Fossil Fuel Subsidies Remain Large: An Update Based on Country-Level Estimates* 5 (Int'l Monetary Fund, Working Paper No. 19/89, 2019) (estimating that global fossil-fuel subsidies represent up to 5 trillion USD globally factoring in the value of externalities).

77. Gregory C. Unruh, *Understanding Carbon Lock-In*, 28 ENERGY POL'Y 817, 817 (2000).

78. David Popp, *Environmental Policy and Innovation: A Decade of Research* 18 (Nat'l Bureau Econ. Rsch., Working Paper No. 25631, 2019); *see also* STERN, *supra* note 24, at 408–09.

79. Daron Acemoglu, Ufuk Akcigit, Douglas Hanley & William Kerr, *Transition to Clean Technology*, 124 J. POL. ECON. 52, 89 (2016).

80. *Id.* at 86–88 (explaining that a subsidy, which changes the direction of innovation, can have an impact on future price distortions that diminishes with time, but could also countervail some of the near-term price distortions caused by carbon taxes).

81. Jaffe, *supra* note 9, at 166–68; Popp, *supra* note 78, at 20–22; Gross et al., *supra* note 34, at 692; *see generally* Vicki Norberg-Bohm, *Creating Incentives for Environmentally Enhancing Technological Change: Lessons From 30 Years of U.S. Energy Technology Policy*, 65 TECH. FORECASTING & SOC. CHANGE 125 (2000) (relying on historical evidence on the electricity market to advocate for both demand-pull and supply-push policies to promote renewable energy innovation and overcome strong externalities in energy production and consumption); Gary E. Marchant, *Complexity and Anticipatory Socio-Behavioral Assessment of Government Attempts to Induce Clean Technologies*, 61 UCLA L. REV. 1858 (2014) (evaluating recent technology-forcing mandates as a last resort solution due to diffi-

latory instruments all have clearly developed roles in the green innovation system. Is there a fruitful role for patent law in this context?

As the later sections discuss, evidence supports the idea that patents help entrepreneurs to get their solutions to market in certain contexts and under specific conditions.[82] However, the suggestion that patents will do little to promote novel solutions does not mean it cannot have serious impacts on reducing GHGs in, for instance, mature technologies, particularly when looking at the maturity of renewable energy and its remarkable progress to date.[83] Though there are limits to the emission reduction potential of mature technologies, behavioral change can overcome some of those shortcomings.[84] While hardly a full answer to the problem, this interpretation seeks to promote realism about where patent law has its impacts for green innovation policy.[85] Or, from a more sobering view, perhaps short-termism[86] and years of inaction on climate targets mean several options are no longer on the table.[87] Of course, advances in breakthrough technologies, such

culties forecasting technological change and the need for adaptive review process to adjust technology programs); Liscow & Karpilow, *supra* note 51 (arguing for the need for a policy that targets green innovation dynamically, using many policy levers targeting different stages of the innovation pipeline).

82. There is an increasing interest in understanding what impacts patents have on capital markets and investors in innovative firms. *See, e.g.*, Long, *supra* note 35; Graham et al., *supra* note 35; Rinehart, *supra* note 35; Graham & Sichelman, *supra* note 35.

83. *See* Francois Lafond et al., *How Well Do Experience Curves Predict Technological Progress? A Method for Making Distributional Forecasts*, 128 TECH. FORECASTING & SOC. CHANGE 104, 114 (2018) (explaining that if the deployment of solar power continues at the current rate, it is likely to become very inexpensive in the near future).

84. *See generally* Anderson, *supra* note 19 (arguing for more transparency about the role technology plays in predictions about the feasibility of addressing climate change — in particular, the tremendous uncertainties about our ability to deploy novel "negative-emissions technologies" at the scale required; and arguing it is likely that without these technologies, climate stabilization will call for a radical reversal of prevailing energy consumption, with immense repercussions our lifestyles and the trajectory of economic growth for years to come).

85. Note also that there are clear limits to patent law when it comes to certain forms of socially valuable innovation. For instance, because patents only reward what can be effectively rendered excludable, patents do not reward certain inventions with tremendous social value — often solutions which are more accessible or low-cost. *See* Amy Kapczynski & Talha Syed, *The Continuum of Excludability and the Limits of Patents*, 122 YALE L.J. 1900, 1902–03 (2013) (providing the example of a non-patentable checklist which effectively reduces the likelihood of contracting life-threatening infections at hospitals).

86. *See generally* Ted O'Donoghue & Matthew Rabin, *Doing It Now or Later*, 89 AM. ECON. REV. 103 (1999) (explaining that cognitive biases generate time-inconsistent present-biased preferences, prioritizing nearer term rewards over the long-term); Larry Karp, *Global Warming and Hyperbolic Discounting*, 89 J. PUB. ECON. 261 (2005) (explaining how policies designed using a constant discount vastly underestimate the long-run environmental damage posed by climate change).

87. Heavy reliance on CDR techniques, for instance, could be construed as a compromise on CO2 emissions abatement.

as hydrogen power, could be game changers.[88] But understanding the relationship between patent incentives and technology maturity can have significant implications.[89] It bears asking why legal scholars still explore whether patents incentivize the early stages of green innovation at all; this oversight is perhaps attributable to a lack of interdisciplinary engagement.

III. PATENT POLICY LEVERS FOR GREEN INNOVATION

A. Patent Law and Climate Change

Despite indications that significant numbers of firms are patenting green technologies,[90] there is much debate over whether patents are an appropriate tool to promote green innovation. These debates emerged in response to Member State negotiations at the United Nations Framework on Climate Change Convention ("UNFCCC")[91] on whether to add IP terms to commitments on green technology transfer from the Global North to the Global South.[92] Notably, the Member States contemplated the weakening of patent protection over green technologies for developing nations, including compulsory licensing provisions.[93] No consensus could be reached because it was thought that weak patent rights diminish firm innovation incentives, an outcome which is widely criticized.[94] While the overwhelming sense

88. *See generally* Michael Ball & Martin Wietschel, *The Future of Hydrogen – Opportunities and Challenges*, *in* THE HYDROGEN ECONOMY: OPPORTUNITIES AND CHALLENGES 613 (Michael Ball & Martin Wietschel eds., 2009).

89. *See infra* Part IV.

90. *See generally* UNEP & EUR. PAT. OFF. [EPO], CLIMATE CHANGE MITIGATION TECHNOLOGIES IN EUROPE — EVIDENCE FROM PATENT AND ECONOMIC DATA 32 (2015), http://documents.epo.org/projects/babylon/eponet.nsf/0/6A51029C350D3C8EC1257F110056B93F/$File/climate_change_mitigation_technologies_europe_en.pdf [https://perma.cc/V59F-DSTG] (finding that patenting of climate change mitigation technologies by Europe-based inventors increased by a factor of five from 1995 to 2011); Lorena Rivera León, Kyle Bergquist, Sacha Wunsch-Vincent, Ning Xu & Kunihiko Fushimi, *Measuring Innovation in Energy Technologies: Green Patents as Captured by WIPO's IPC Green Inventory*, 6–7 (World Intell. Prop. Off., Working Paper No. 44, 2018), https://www.wipo.int/publications/en/details.jsp?id=4351&plang=EN [https://perma.cc/C5NB-XF4E] (finding that international patent applications have grown 173%, from 6,546 in 2005 to 17,880 in 2013); IEA, *supra* note 30, at 322–23 (finding that overall green patenting peaked around 2011, declining since largely due to the maturation of renewable energy technology).

91. United Nations Framework Convention on Climate Change, *opened for signature* June 4, 1992, 1771 U.N.T.S. 107 (entered into force Mar. 21, 1994).

92. Paris Agreement, *supra* note 1, art 4(5).

93. *See generally* Jérôme de Meeûs & Alain Strowel, *Climate Change and the Debate Around Green Technology Transfer and Patent Rules: History, Prospects and Unresolved Issues*, 3 WORLD INTELL. PROP. ORG. J. 179 (2012) (providing a retrospective on the UNFCCC debates).

94. *See* Joshua D. Sarnoff, *The Patent System and Climate Change*, 16 VA. J.L. & TECH. 301, 303–06 (2011) (criticizing the outcome of the Cancun Agreement for its failure to

amongst legal scholars is that patents are likely to interfere with progress on climate goals, there is little agreement on the solutions to this problem.

Ofer Tur-Sinai captures the patent "skeptic's view": as a market mechanism, patents provide suboptimal incentives because green technologies represent a shift towards less fossil fuel-intensive activity.[95] Only radical reforms to patent law could overcome this defect in its incentive mechanism — which in any case are likely insufficient without accompanying non-market mechanisms.[96] Climate prizes, or rewards, are increasingly popular alternatives.[97] The pragmatists, however, start from the premise that reforming patent law is preferable, or at least more practicable, than patent suspension. Their reforms are wide-ranging, including exclusions to patentability, enhanced experimental use defenses, or collaborative licensing models.[98] But which of these policy levers bear promise? And why is there such disagreement over whether patents are appropriate incentives for

agree upon binding funding commitments, or the inclusion of mandatory intellectual property law provisions to develop and transfer environmentally friendly technologies, arguing it constitutes an implicit choice to rely on private market-led innovation, which prejudices access to technology for developing nations who cannot afford the costs of patented technologies). *But see* Estelle Derclaye, *Not Only Innovation but also Collaboration, Funding, Goodwill and Commitment: Which Role for Patent Laws in Post-Copenhagen Climate Change Action*, 9 J. MARSHALL REV. INTELL. PROP. L. 657, 658 (2010) (suggesting the exclusion of mandatory IP terms may not be terribly significant because (1) funding and other technology transfer mechanisms may be more effective and (2) parties may voluntarily share intellectual property or license on preferable terms to meet technology transfer obligations under the UNFCCC in any case). Notably, a policy document released contemporaneously predicted that private actors are likely to underinvest in green technologies, and that significant public sector investment would be needed for climate stabilization. *See* GWYN PRINS ET AL., THE HARTWELL PAPER: A NEW DIRECTION FOR CLIMATE POLICY AFTER THE CRASH OF 2009 31–32 (2010), https://eprints.lse.ac.uk/27939/1/HartwellPaper_English_version.pdf [https://perma.cc/5M4E-UZ42]. For a general overview of the approaches of the literature since then, see generally Matthew Rimmer, *Introduction: The Road to Paris: Intellectual Property, Human Rights, and Climate Justice*, *in* INTELLECTUAL PROPERTY AND CLEAN ENERGY: THE PARIS AGREEMENT AND CLIMATE JUSTICE 1 (Matthew Rimmer ed., 2018).

95. *See, e.g.*, Tur-Sinai, *supra* note 12, at 214, 250 (expressing skepticism that a status quo patent system will encourage green innovation); Drahos, *supra* note 12, at 42 (explaining why there are inherent limits to the utility of patent reform: for instance, extending patent term, whilst increasing the patent reward, would likely be insufficient to encourage risk-averse, private actors to invest in the basic science behind green technologies).

96. *See, e.g.*, Tur-Sinai, *supra* note 12, at 251–60 (explaining that several supply-side and demand-side interventions will be needed to encourage green innovation, such as public funding commitments and command-and-control regulation).

97. *See, e.g.*, Gregory N. Mandel, *Promoting Environmental Innovation with Intellectual Property Innovation: A New Basis for Patent Rewards*, 24 TEMP. J. SCI. TECH. & ENV'T L. 51, 64–65, 69 (2005).

98. *See, e.g.*, Matthew Rimmer, *A Proposal for a Clean Technology Directive: European Patent Law and Climate Change*, 2 RENEWABLE ENERGY L. & POL'Y REV. 195, 199, 202, 204 (2011) (contending that the European Union ought to take on a more active and collaborative role around intellectual property and climate change at the international level, to create "Climate Innovation Centres," which would use, *inter alia*, patent pools to share patented technologies).

green technologies? This Part examines the main arguments in the literature in light of the wider innovation context.

B. The Skeptics

The skeptics' view rests on the disadvantages to the use of patents as mechanisms driven by market demand to incentivize innovation. This incentive mechanism cannot encourage a whole host of innovations that are socially valuable but not profitable because it relies on a consumer-pays model for innovation.[99] Patents are exclusive rights over inventions which proffer an incentive to invent that enables inventors to recoup the costs of R&D. Tur-Sinai summarizes the problem: patents act on existing market incentives; they do not *create* incentives.[100] Thus, price signals direct patenting towards technologies with higher profitability, or more proximate payoffs. One implication is that patents do little to encourage the basic science behind much green innovation.[101] Basic science is either not eligible for patentability, or encounters so many knowledge spillovers during R&D that it would not be cost-effective.[102] Patents are more likely to encourage expensive, high-technological solutions over simple, cheaper solutions.[103] The problem is acute for green innovation because, without proper carbon pricing, price signals for investment in green innovation are suppressed.[104]

However, there are conceptual problems with this account. First, the market forces characterization is over-simplified. Consumer preferences for goods that do not yet exist are not reflected in current market demand, but it more closely resembles an "inchoate demand."[105] Initially, there is little demand for new technologies, but as consumers become aware of the options, articulated market demand

99. Rochelle C. Dreyfuss, *The Challenges Facing IP Systems: Researching for the Future*, *in* 4 KRITIKA: ESSAYS ON INTELLECTUAL PROPERTY 1, 12 (Peter Drahos et al. eds., 2020) (noting that the patent system customarily serves the needs of those who can pay, barring cures for diseases from poorer populations or the technologies needed to combat climate change).

100. Tur-Sinai, *supra* note 12, at 226.

101. Drahos, *supra* note 12, at 42.

102. *See* Nelson, *supra* note 37, at 302.

103. Since patents, as exclusionary rights, disfavor simple, cheaper solutions that would be more accessible to poorer populations, they perform inadequately when it comes to encouraging innovation for poorer populations. *See* Navi Radjou, Jaideep Prabhu & Simone Ahuja *Frugal Innovation: Lessons from Carlos Ghosn, CEO, Renault-Nissan*, HARV. BUS. REV. (July 2, 2012), https://hbr.org/2012/07/frugal-innovation-lessons-from [https://perma.cc/5S6B-K8HR] (describing how Renault-Nissan came to use "frugal engineering" to produce cheaper automotive vehicles for developing nations, and further describing the opportunities in emerging markets for firms willing to take on "frugal innovation").

104. Tur-Sinai, *supra* note 12, at 235–36.

105. PAUL A. GEROSKI, THE EVOLUTION OF NEW MARKETS 29–30 (2003) (defining inchoate demand "the demand for products which do not as yet exist").

for those goods forms.[106] Second, as a theoretical hypothesis based on unrealistic assumptions, it is unclear that the DEP (double externality problem) uniformly suppresses patenting in green technologies. Incorporating realism into the model comes with many qualifications, however. For instance, the DEP would not have the same impacts on not-for-profit research.[107] Moreover, the DEP is an argument for proper carbon pricing, not for patent skepticism — it does not analyze patent aspects of the problem substantively. And though patenting does not drive basic science, that activity is typically regarded to fall on public sector financing in any case.[108] There are genuine concerns about the effects of patent law on developing nations, though this is ultimately an issue of access and not of incentives. Most green innovation emanates from the United States, Japan, Korea, Europe, and China.[109] Whether developing nations gain expeditious access to green technology is a pressing concern, but this has narrow implications for domestic policy in the countries where most innovation occurs.

Seeing the limits to patents as incentives, the skeptics advocate prizes and rewards. For example, under Gregory Mandel's rewards scheme, the state would take ownership of essential green technologies in exchange for compensation.[110] Mandel contends this means incentives to invent are designed around a technology's social benefits, not profit motives.[111] As non-market instruments, prizes can incorporate environmental standards.[112] Prizes are said to achieve substantially the same incentive effect as patents, but without the accruing deadweight losses of property rights.[113] Prizes are typically efficacious in scenarios where goals are set but the route to achieving them is unclear, and where the social value of a technology far exceeds its private return.[114] The idea is that prizes are better alterna-

---

106. *Id.*

107. Nordhaus, *supra* note 46, at 670–71.

108. *See* Nelson, *supra* note 37, at 304–05.

109. UNEP & EPO, *supra* note 90, at 34–35.

110. Mandel, *supra* note 97, at 64.

111. Gregory N. Mandel, *Innovation Rewards: Towards Solving the Twin Market Failures of Public Goods*, 18 VAND. J. ENT. & TECH. L. 303, 314 (2016).

112. Tur-Sinai, *supra* note 12, at 253.

113. *See* Nancy Gallini & Suzanne Scotchmer, *Intellectual Property: When is it the Best Incentive System?*, 2 INNOVATION POL'Y & ECON. 51, 55 (2002) (clarifying that if "an investment's prospective value is known to the sponsor . . . [and] the sponsor can screen projects himself . . . [the] prize system then seems superior to IP . . . [since it] avoids deadweight loss, and can be as good as IP at motivating effort"). *But see* Brian D. Wright, *The Economics of Invention Incentives: Patents, Prizes, and Research Contracts*, 73 AM. ECON. REV. 691, 703 (1983) (explaining that the relative advantage to using a patent over a prize or research contract depends, *inter alia*, on the level of private information firms hold by contrast to a public administrator).

114. Michael J. Burstein & Fiona E. Murray, *Innovation Prizes in Practice and Theory*, 29 HARV. J.L. & TECH. 401, 415–16 (2016).

tives to patents so long as market incentives for green innovation are suppressed.[115] But there are practical limits: how do governments predict a technology's social value ex. ante, and will their metrics not invariably involve price considerations even as a proxy for social value?[116]

In theoretical terms, prizes have numerous advantages over patent protection. The actual implementation and operation of a prize system, however, complicates comparisons.[117] Theoretical prizes are substitutes for patents, but prizes in action are generally *complements*.[118] That is, as prize demand increases, prices for patents decrease. At the very least, prizes are often *supplementary* to patent protection.[119] Complementarity, however, means that the differences between patents and prizes are slim when looking at the comparable quantum of their deadweight losses.[120] For government-funded prizes, of course, the deadweight losses function differently, as they are spread out among a larger number of consumers, for instance through taxation.[121] But then there is the problem of scale: prizes can incentivize the development of a new invention, but are not of a sufficient magnitude for the expense of upscaling a commercially-viable product. However, prizes are vulnerable to the criticisms of rent-seeking and picking winners that traditionally bolstered justifications for patents in the first place.[122] With fine distinctions between patents and prizes, their merits should be determined on a case-by-case basis.

It remains worrying, however, that patent law has the potential to impede technological advance, with terrible repercussions. Patents have been used to raise prices during times of crises, such as over the much-needed Tamiflu during the avian flu crisis of 2004–2005.[123]

115. Joy Y. Xiang, *Cleantech Innovations by Developing Countries*, 38 B.U. INT'L L.J. 183, 231 (2020).

116. *See* Estelle Derclaye, *Not Only Innovation but also Collaboration, Funding, Goodwill and Commitment: Which Role for Patent Laws in Post-Copenhagen Climate Change Action*, 9 J. MARSHALL REV. INTELL. PROP. L. 657, 663 (2010).

117. *See* Daniel J. Hemel & Lisa Larrimore Ouellette, *Beyond the Patents-Prizes Debate*, 92 TEX. L. REV. 303, 326–27 (2013); Gallini & Scotchmer, *supra* note 113, at 54–55; *see generally* Benjamin N. Roin, *Intellectual Property versus Prizes: Reframing the Debate*, 81 U. CHI. L. REV. 999 (2014).

118. Burstein & Murray, *supra* note 114, at 411.

119. *Id.*

120. Roin, *supra* note 117, at 1045–73 (criticizing the common contention that prizes are more advantageous than patents, specifically, in comparing the deadweight losses of intellectual property as against the proposed gains in price competition a prize brings about).

121. Heidi Williams, *Innovation Inducement Prizes: Connecting Research to Policy*, 31 J. POL'Y ANALYSIS & MGMT. 752, 757 (2012).

122. Gary E. Marchant, *Sustainable Energy Technologies: Ten Lessons from the History of Technology Regulation*, 18 WIDENER L.J. 831, 836–39 (2009) (explaining through case studies why open-ended goals are preferable to picking winners in environmental technology policy). On rent-seeking, *see generally* Gordon Tullock, *The Welfare Costs of Tariffs, Monopolies, and Theft*, 5 ECON. INQUIRY 224 (1967).

123. Drahos, *supra* note 12, at 39–40.

Patent hold-up for green technology could imperil the developing nations most vulnerable to the impacts of climate change, which can have weak homegrown IP regimes and can be reliant on access to technologies from the Global North.[124] It can also stall sequential advances. In biofuels, for instance, patent hold-up on a single patented enzyme can stall a variety of second-generation innovations.[125] Deployment of mature technologies can be hindered too, as patented green technologies often relate to multiple industries and rely on interoperability.[126] Patent use, or *misuse*, and the resultant impacts on climate stabilization, are particularly concerning.

Relatedly, coordinating efficient licensing can be complex, posing challenges for technologies that rely on integration and interoperability, such as smart grids.[127] Patenting outputs of publicly funded research can facilitate licensing, but it also raises the possibility that those patents can block downstream innovation or sequential advances.[128] The so-called "anticommons" problem in biomedical research is a case in point.[129] Already, Toyota has extensively litigated over its hybrid vehicle patents.[130] And it is suggested that non-practicing entities are emerging in the smart grids, accumulating patent portfolios over technologies they never intend to use, so as to trigger strategic litigation and extract rents.[131] But while raising interesting questions,

---

124. Keith E. Maskus & Ruth L. Okediji, *Legal and Economic Perspectives on International Technology Transfer in Environmentally Sound Technologies*, *in* INTELLECTUAL PROPERTY RIGHTS: LEGAL AND ECONOMIC CHALLENGES FOR DEVELOPMENT 392, 393 (Mario Cimoli et al. eds., 2014); Abbe E.L. Brown, *Intellectual Property and Climate Change*, *in* THE OXFORD HANDBOOK OF INTELLECTUAL PROPERTY LAW 958, 989 (Rochelle Dreyfuss & Justine Pila eds., 2018) (noting that "there is still the hypothetical (and as some would argue, a real) risk that if a technology that is protected by IP rights becomes very important, the rights holder could limit the progression of the market and interfere with action against climate change.").

125. *See* Maskus & Okediji, *supra* note 124, at 396.

126. Kane Wishart, *Management of Intellectual Property in Australia's Clean Technology Sector: Challenges and Opportunities in an Uncertain Regulatory Environment*, *in* INTELLECTUAL PROPERTY AND CLEAN ENERGY: THE PARIS AGREEMENT AND CLIMATE JUSTICE 177, 183–84 (Matthew Rimmer ed., 2018).

127. *See generally* Scotchmer, *supra* note 63 (explaining the complex variables that affect propensity to license between pioneer and sequential innovators).

128. *See* Joshua D. Sarnoff, *Government Choices in Innovation Funding (with Reference to Climate Change)*, 62 EMORY L.J. 1087, 1104 (2013).

129. Michael A. Heller & Rebecca S. Eisenberg, *Can Patents Deter Innovation? The Anticommons in Biomedical Research*, 280 SCIENCE 698, 698 (1998). *Contra* David Lametti, *The Concept of the Anticommons: Useful, or Ubiquitous and Unnecessary?*, *in* CONCEPTS OF PROPERTY IN INTELLECTUAL PROPERTY LAW 232, 255–57 (Helena R. Howe & Jonathan Griffiths eds., 2003) (arguing that the anticommons concept is a strawman and that theories of property are already equipped with solutions to inefficient fragmentation of ownership).

130. *See* MATTHEW RIMMER, INTELLECTUAL PROPERTY AND CLIMATE CHANGE: INVENTING CLEAN TECHNOLOGIES 197–235 (2011); ERIC L. LANE, CLEAN TECH INTELLECTUAL PROPERTY: ECO-MARKS, GREEN PATENTS, AND GREEN INNOVATION 120–36 (2011).

131. Eric L. Lane, *Keeping the LEDs on and the Electric Motors Running: Clean Tech in Court after eBay*, DUKE L. & TECH. REV., No. 013, Sept. 22, 2010, at 1, 27–28.

there is little empirical evidence on entrepreneurial activity. Rather than deliberating about the optimal patent incentive mechanism, there is a pressing need to understand how patents are affecting green technology commercialization.

C. The Pragmatists

A number of pragmatist arguments seek to use patent law alongside environmental regulation to accelerate green innovation or lower its costs. Natalie Derzko proposes a green patent regime modelled on collaboration between the United States Patent and Trademark Office and the Environmental Protection Agency.[132] Patents would be complemented by "innovation waivers," which are grace periods over regulatory permit requirements for post-prototype technologies, that expedite the time between invention and commercialization.[133] The success of patent office reforms to date may undergird that proposal. Several patent offices have varying green patent application fast-tracking and tagging schemes.[134] These decrease what can be a wait of up to four years for patent grants.[135] For instance, the European Patent Office uses "Y02" subclasses to publicize green technologies on the patent register and to make patent searches easier.[136] With proven benefits, these procedural reforms should be expanded.

The more extreme views advocate significant change to patent law. Estelle Derclaye proposes use of the "ordre public" exclusion from patentability to exclude environmentally harmful technologies, noting that environmental impact has already entered into the balancing exercise under Article 27.2 of the Agreement on Trade-Related Aspects of Intellectual Property Rights[137] ("TRIPS").[138] Others are more skeptical of its practicability.[139] While "ordre public" has en-

132. Derzko, *supra* note 48, at 15.

133. *Id.* at 22–31, 35–36.

134. *See generally* Antoine Dechezleprêtre, *Fast-Tracking Green Patent Applications: An Empirical Analysis* (Grantham Research Institute on Climate Change and the Environment Working Paper No. 127, 2013) (demonstrating that the United Kingdom, United States, Australia, Republic of Korea, Japan, Israel, and Canada have comparable green patent application schemes).

135. *Id.* at 19.

136. EPO, FINDING SUSTAINABLE TECHNOLOGIES IN PATENTS, 7–13 (2016), http://documents.epo.org/projects/babylon/eponet.nsf/0/6E41C0DF0D85C0ACC125773B005144DE/$File/finding_sustainable_technologies_in_patents_2016_en.pdf [https://perma.cc/3B9H-T3ZZ].

137. Agreement on Trade-Related Aspects of Intellectual Property Rights art. 27(2), Apr. 15, 1994, Marrakesh Agreements Establishing the World Trade Organization, Annex 1C, 1869 U.N.T.S. 299.

138. Derclaye, *supra* note 13, at 273–74; *see* Plant Genetic Sys. N.V. v. Greenpeace Ltd., T 0356/93, 1995 O.J. E.P.O. 545 at Reasons ¶ 3 (describing application of the *ordre public* provision to examine whether an invention seriously prejudices the environment).

139. Rimmer, *supra* note 98, at 199–200; Joshua D. Sarnoff, *Intellectual Property and Climate Change, with an Emphasis on Patents and Technology Transfer*, *in* THE OXFORD

countered renewed attention to regulate the policy impacts of biotechnology and emerging technologies, presently, it is a purely theoretical possibility.[140] Alternatively, Matthew Rimmer contends that a European "Clean Technology Directive" ought to harmonize a package of specialized patent provisions for green technologies, a proposal motivated by the paradox of the EU's proactive stance on climate change versus its regressive position on strong IP rights in international law.[141] But whatever benefits may have accrued to these reforms in years past simply do not hold water when considering the short time left to avert irreversible impacts of climate change.

Proposals to weaken patent protection, however, have the potential to negatively impact green innovation, without offering robust evidence as to the benefits. Wei Zhuang explores the possibility of a declaration for climate change analogous to the Doha Declaration under the TRIPS Agreement.[142] Such compulsory licensing provisions for green technologies seek to ensure the Global South can access green technology in times of crisis. However, the limited efficacy of compulsory licensing for medicines to date hardly augurs well for green innovation.[143] Moreover, there are existing provisions for green compulsory licensing in the United States, but these provisions have never been triggered.[144] In any case, it is unclear that a single compulsory license can provide significant assistance. Unlike the one lifesaving drug, however idealized that scenario may be, green technolo-

---

HANDBOOK OF INTERNATIONAL CLIMATE CHANGE LAW 391, 403 (Kevin R. Gray et al. eds., 2016).

140. Justine Pila, *Adapting the Ordre Public and Morality Exclusion of European Patent Law to Accommodate Emerging Technologies*, 38 NATURE BIOTECHNOLOGY 555, 557 (2020).

141. Rimmer, *supra* note 98, at 197–98.

142. *See generally* WEI ZHUANG, INTELLECTUAL PROPERTY RIGHTS AND CLIMATE CHANGE: INTERPRETING THE TRIPS AGREEMENT FOR ENVIRONMENTALLY SOUND TECHNOLOGIES, 278–307 (2017) (outlining the rationale for provisions to trigger compulsory licensing under the TRIPS Agreement as well as the substantive requirements of compulsory licensing, and analyzing its use in healthcare to reflect on the possible use of compulsory licensing for climate-friendly technologies).

143. *See* JOHANNA GIBSON, INTELLECTUAL PROPERTY, MEDICINE AND HEALTH: CURRENT DEBATES, 151–60, 164–66 (2d ed. 2018); *see generally* Mario Gaviria & Burcu Kilic, *A Network Analysis of COVID-19 mRNA Vaccine Patents*, 39 NATURE BIOTECHNOLOGY 546 (2021) (indicating the complexity involved in ensuring access to the COVID-19 vaccination using licensing over the many intellectual property rights that cover even a single vaccine); Amy Maxmen, *In Shock Move, US Backs Waiving Patents on COVID Vaccines*, NATURE: NEWS (May 6, 2021), https://www.nature.com/articles/d41586-021-01224-3 [https://perma.cc/6VLK-T2F8] (noting that despite support for a patent waiver over the COVID-19 vaccine from the United States, the World Trade Organization "will not negotiate the details of which patents to adjust until all its member countries agree on some sort of waiver").

144. *Compare* Derclaye, *supra* note 13, at 282, *with* Derek Eaton, *Technology and Innovation for a Green Economy*, 22 REV. EUR. COMPAR. & INT'L ENV'T L. 62, 66 (2013) (arguing that it is trade, licensing, and foreign direct investment that drives green technology transfer).

gies often rely on multiple patents.[145] But compulsory licensing may adversely impact the late stages of innovation.[146] While the existential threat of climate change justifies considering all options, there is little evidence to recommend weakening patent protection over green technologies.

However, the arguments for a mixed policy importantly signal the need for increased collaboration between public and private actors. On the international stage, the World Intellectual Property Office could standardize green patenting terms to prevent disjointed practices at patent offices.[147] Patent offices could use application fees to subsidize licensing for developing nations, or even establish a green innovation fund.[148] Specialized licensing arrangements are promising. For instance, humanitarian licensing can preserve strong IP rights but procure access to technology for developing nations, while non-exclusive licensing can reduce the costs of access by reducing infringement risks.[149] Tesla, for example, made its electric battery patent portfolios open-source for green innovators.[150] However, Tesla has historically accumulated IP portfolios aggressively, and its pledge comes with a good faith requirement: leaving the patentee wide discretion to revoke usage rights.[151] Moreover, green patent 'pooling' was attempted in the Eco-Patent Commons and the Green-Xchange, though both initiatives lacked the infrastructure or direction to succeed.[152] While valuable

145. Robert Fair, *Does Climate Change Justify Compulsory Licensing of Green Technology?*, 6 INT'L L. & MGMT. REV. 21, 37–38 (2009).

146. CÉDRIC PHILIBERT & JACEK PODKANSKI, INTERNATIONAL ENERGY AGENCY TECHNOLOGY COLLABORATION AND CLIMATE CHANGE MITIGATION: CASE STUDY 4: CLEAN COAL TECHNOLOGIES 5 (2005), https://www.oecd.org/environment/cc/34878689.pdf [https://perma.cc/QS4F-94UD] (suggesting that weak international patent protection has impeded clean coal technology diffusion from developed nations to the developing world).

147. *See* Scott Taylor, *Where are the Green Machines: Using the Patent System to Encourage Green Invention and Technology Transfer*, 23 GEO. INT'L. ENV'T L. REV. 577, 600–04 (2011); Mervyn D. Jones, *A View from Inside the Renewable Energy Industry*, *in* ENVIRONMENTAL TECHNOLOGIES, INTELLECTUAL PROPERTY AND CLIMATE CHANGE: ACCESSING, OBTAINING AND PROTECTING 265, 270 (Abbe E.L. Brown ed., 2013).

148. Itaru Nitta, *Proposal for a Green Patent System: Implications for Sustainable Development and Climate Change*, 5 SUSTAINABLE DEV. L. & POL'Y, Spring 2005, at 61, 63; *cf.* Maskus and Okediji, *supra* note 124, at 400–02.

149. Andrea Nocito, *Innovators Beat the Climate Change Heat with Humanitarian Licensing Patent Tools*, 17 CHI. KENT J. INTELL. PROP. 164, 182–87 (2017).

150. Matthew Rimmer, *The Paris Agreement: Intellectual Property, Technology Transfer, and Climate Change*, *in* INTELLECTUAL PROPERTY AND CLEAN ENERGY: THE PARIS AGREEMENT AND CLIMATE JUSTICE 33, 46–47 (Matthew Rimmer ed., 2018).

151. Matthew Rimmer, *Elon Musk's Open Innovation: Tesla, Intellectual Property, and Climate Change*, *in* INTELLECTUAL PROPERTY AND CLEAN ENERGY: THE PARIS AGREEMENT AND CLIMATE JUSTICE 515, 524 (Matthew Rimmer ed., 2018).

152. JORGE L. CONTRERAS, BRONWYN H. HALL & CHRISTIAN HELMERS, ASSESSING THE EFFECTIVENESS OF THE ECO-PATENT COMMONS: A POST-MORTEM ANALYSIS 1, 16–17 (2018), https://www.cigionline.org/sites/default/files/documents/Paper%20no.161_4.pdf [https://perma.cc/H6U6-ZYA2]; Roya Ghafele & Robert D. O'Brien, *Open Innovation for Sustainability Lessons from the GreenXchange Experience, An ICTSD Policy Brief*, 1 INT'L J. ECON. BEHAV. & ORG. 13, 16–17 (2013).

experiments, collaborative schemes appear to require more clearly articulated goals.[153] There is increasing awareness as to the potential gains of public-private collaborations to drive innovation, although the possible transformations of patent law have yet to be realized. Moreover, policy prescription is partly a communication of the nature of the problem, and the feasibility of its solutions. There is no public sector deus ex machina for climate catastrophe, but a necessary role for the public sector is to direct and harness potential collaborations from the growing private interest in green energy markets.

D. What about Firms that Patent?

The absence of discourse on green technology markets within these accounts, however, is conspicuous.[154] There are several credible explanations for this omission. First, the tendency to focus on the ex ante incentive effects of patents in the literature means that the ex post effects of patent law on firm activity and the dissemination of technology is undertheorized. It can only be assumed that concerns about the DEP are partly behind the commentary on the faults of the patent incentive. But it is not clear that patenting in green technologies have been suppressed. Second, the examination of patent incentives leads to a focus on novel technology in the legal literature.[155] Third, by confining analysis of patent law's ex post effects to the issue of access to technology, there is a significant gap in understanding how firms use patents to disseminate technology. And at the same time, with pervasive uncertainty over the pathways to emission reductions, some of the best technological options are perhaps already in existence.[156] Patents may be inappropriate incentive mechanisms for early green innovation when looking at the role of public research programs.[157] For mature technologies, however, rapid commercialization and diffusion is now decisive. It is in this later stage of the innovation pipeline that patents are said to make a difference — and it is worth understanding

153. Acute emergencies, such as the COVID-19 pandemic, have encouraged more effective and collaborative intellectual property schemes because the demands of the COVID-19 crisis are determinate. *See* OPEN COVID PLEDGE, https://opencovidpledge.org/ [https://perma.cc/3TDW-EE36] (stating its goal to "pledge to make our intellectual property available free of charge for use in ending the COVID-19 pandemic"). By contrast, collaborative intellectual property schemes motivated by climate change have previously described their aims as too general to be effective.

154. There are valuable contributions to begin mapping the patenting activity of green entrepreneurs, but these accounts are somewhat anecdotal, with no systematic study of entrepreneurs' motivations for patenting, and the uses of patent law for green business strategies. *See, e.g.*, Rimmer, *supra* note 94; LANE, *supra* note 130.

155. *See supra* Sections III.B-C.

156. *See* Gross et al., *supra* note 34, at 691–92 (arguing that relying on breakthrough technologies "risks taking too long to deliver the solutions needed for climate change").

157. *See supra* Part II.

if serious contemplation of how patents affect green innovation is needed.

Yet firm patent practices in green energy technologies are understudied, beyond the mapping of patent application statistics. Part IV of this Note focuses on one of the open questions posed by firm patenting in green technologies: what role patents play in technology commercialization by start-up entrepreneurs.[158] It encourages moving beyond doctrinal analysis of innovation problems for patent law towards interdisciplinary approaches. The innovation system concept is one such framework to compare patents against other policy tools to determine when it is the most effective tool to promote innovation.

IV. PATENTS AND TECHNOLOGY COMMERCIALIZATION

A. Entrepreneurs

The idea that entrepreneurs are the key to innovation is not new, though it has received renewed attention in relation to green technologies. Start-up entrepreneurs may be especially influential on the green innovation market.[159] With the maturation of renewable energy and the declining value of oil, incumbent energy providers are increasingly investing in green energy, rapidly expanding entrepreneurial activity.[160] Present knowledge indicates that the green start-up scene is thriving.[161] Yet the research on green start-ups is still young.[162] Moreover, IP research has only recently begun to investigate entre-

158. The comments in the next part are partly motivated by reflections from the early stages of an empirical project which interviews British–based green energy entrepreneurs.

159. Linda Bergset & Klaus Fichter, *Green Start-Ups — A New Typology for Sustainable Entrepreneurship and Innovation Research*, 3 J. INNOVATION MGMT. 118, 121 (2015) (arguing that although studies on green start-ups are still nascent, green start-ups appear to have a greater impact on innovation by comparison to start-ups generally); *see generally* Kai Hockerts & Rolf Wüstenhagen, *Greening Goliaths versus Emerging Davids — Theorizing About the Role of Incumbents and New Entrants in Sustainable Entrepreneurship*, 25 J. BUS. VENTURING 481 (2010) (noting that start-ups are more likely than market incumbents to innovate in green solutions).

160. CELINE HERWEIJER, KIRAN SURA, BENJAMIN COMBES & MATT GILBERT, NET ZERO ECONOMY INDEX 2020: THE PIVOTAL DECADE 12 (2020), https://www.pwc.co.uk/sustainability-climate-change/net-zero-2020/the-net-zero-economy-index-2020.pdf [https://perma.cc/M8YV-9Y97] (estimating that venture capitalists invested 60 billion USD in over 1200 climate technology start-ups between 2013 and 2019); *see also* Roula Khalaf et al., *BP's Looney Stakes Future on Producing Less Oil*, FIN. TIMES (Sept. 13, 2020), https://www.ft.com/content/e1d53208-b460-4708-a89c-d8b418cceffb [https://perma.cc/CHM5-838S].

161. CELINE HERWEIJER, BEN COMBES, TARIK MOUSSA, JAMES WARK, JESS WRIGLEY & MARISA DONNELLY, THE STATE OF CLIMATE TECH 2020 14 (2020) https://www.pwc.com/gx/en/services/sustainability/assets/pwc-the-state-of-climate-tech-2020.pdf [https://perma.cc/9P4J-8E6V] (explaining that from 2013 to 2019, the global growth rate in green start-ups represented more than five times the growth rate of the wider venture capital industry).

162. Popp, *supra* note 78, at 35.

preneurs.[163] Studying entrepreneurs may augment theoretical propositions with an understanding of practice — notably, whether patents are significant at all for green entrepreneurs, or whether informal strategies or alternative IP rights are used.[164]

While the literature critically examines patent law's ex ante incentive effects or measures that expedite patent grants, what happens after the patent office is undertheorized.[165] Perhaps it comes down to the technical and imprecise nature of exercises to determine the maturity of technology.[166] This Note contends that while much is written on patent law's ex ante incentive, its ex post effects — notably, on commercialization — are marginalized to an issue of access to technology.[167] We simply do not know who uses green patents, or if patents are used at all once granted.[168] Note, of course, that patents impact market-based innovative activity, and their significance does not end at invention. However, there is little examination of how patents affect green technology commercialization and diffusion.[169]

Focusing on commercialization, earlier studies have explored how entrepreneurs use patents to get solutions to market. Paradigmatically, patents are used to attract project investment, or to exploit licensing revenues. Patenting can be particularly important for market entrants: by facilitating financing, by acting as a stamp that legitimates new technologies, or by providing a credible signal of firm in-

163. *See generally* Long, *supra* note 35; Graham et al., *supra* note 35; Rinehart, *supra* note 35; Graham & Sichelman, *supra* note 35.

164. Paradigmatically, trade secrets protection is seen as an alternative to patent protection, but there is a growing awareness of the role of alternative protection such as trademarks in firm innovative activity. *See generally* Dev Gangjee, *Trade Marks and Innovation?*, *in* RESEARCH HANDBOOK ON TRADEMARK LAW REFORM 192 (Graeme B. Dinwoodie & Mark Janis eds., 2021) (describing three principle shifts in thinking about the relationship between trademarks and innovation; for instance, the idea that trademarks act in a "feedback cycle" that allow firms to recoup past investments in innovation, or to re-invest profits in future investments in innovation).

165. *See* Taylor, *supra* note 147, at 581–88; Lane, *supra* note 131, at 1–2.

166. *See* Rimmer, *supra* note 98, at 195, 199; *see also* Estelle Derclaye, *Patent Law's Role in the Protection of the Environment – Re-Assessing Patent Law and Its Justifications in the 21st Century*, 4 INT'L REV. INTELL. PROP. & COMPETITION L. 249, 267 (2009). *Compare* Sarnoff, *supra* note 94, at 308, *and* Tur-Sinai, *supra* note 12, at 222–23 (listing important green technologies), *with* Taylor, *supra* note 147, at 582 (arguing that green technological solutions are needed to meet energy demand without capping productivity).

167. *See* Mark A. Lemley, *Ex Ante Versus Ex Post Justifications for Intellectual Property*, 71 U. CHI. L. REV. 129, 130 (2004) (explaining that mainstream theorizing is divided into ex ante or ex post analysis).

168. Mark A. Lemley, *Rational Ignorance at the Patent Office*, 95 NW. U. L. REV. 1495, 1503–04 (2001); *see also* Tur-Sinai, *supra* note 12, at 224–25 (explaining that rising patent application rates say little on what inventions are made but not patented); Sarnoff, *supra* note 94, at 303 (arguing that mass public funding will encourage much private activity).

169. While this Note focuses on commercialization, the preceding analysis has general implications on technology diffusion also.

formation to potential investors.[170] But patent scope and licensing also affects relations between early and later innovators.[171] Because energy innovation covers many different industries, the policy issues for patent law are more complex, and it is difficult to imagine licensing models that are not industry-specific, or even technology-specific.[172] Moreover, patents can be difficult to detect. Note, for instance, in smart energy grid infrastructure, there is a risk of technology lock-in for technical standards where undetected patents may be used to collect rents later.[173] Effectively coordinated licensing could be instrumental to circumventing these issues, given that standardization is key to achieving economies of scale and has known environmental benefits.[174] But of course, these suggestions are only speculative, based on earlier studies of patent use by entrepreneurs.[175] The surface has barely been scratched. Understanding the full impact of patent law requires looking beyond IP to the broader innovation context.

B. Towards the Innovation System

Disagreement over the appropriate response from the patent system is reflective of the complex challenge climate change poses for innovation policy. First, environmental problems — and climate

---

170. *See* L.L.J. Meijer, J.C.C.M. Huijben, A. van Boxstael & A.G.L. Romme, *Barriers and Drivers for Technology Commercialization by SMEs in the Dutch Sustainable Energy Sector*, 112 RENEWABLE & SUSTAINABLE ENERGY REVS. 114, 121 (2019); Foxon et al., *supra* note 44, at 2133; *see also* Graham et al., *supra* note 35, at 1305; F. Scott Kieff, *On the Economics of Patent Law and Policy*, *in* PATENT LAW AND THEORY: A HANDBOOK OF CONTEMPORARY RESEARCH 3, 42–43 (Toshiko Takenaka ed., 2008); Long, *supra* note 35, at 628, 647–48, 656–58 (noting that, in capital markets with asymmetric information between investors and innovative firms, patents may provide a signal of credible firm information to investors — an informational function of patents which in some cases may be more valuable to its owner than the substance of the patent right itself).

171. Scotchmer, *supra* note 63, at 30 (explaining the need to analyze patent scope with the regard to the division of profits between pioneer patentees and improvers).

172. Innovation in components for solar photo-voltaic panels, for instance, may be described as cumulative; however, patterns of technological advance in biofuel technologies could be said to be characterized by discrete, or science-based innovation. The implications for patent scope and the related licensing issues vary greatly depending on these industry-specific, or even technology-specific characteristics. *See* Merges & Nelson, *supra* note 39, at 893–96, 904–08 (describing the implications for optimal patent scope based on three industry-specific patterns of technological advance as being "discrete," "cumulative," and "science-based").

173. Jorge L. Contreras, *Standards, Patents, and the National Smart Grid*, 32 PACE L. REV. 641, 642 (2012).

174. Grubler et al., *supra* note 43, at 1687 (noting that France's success relative to the United States in nuclear technology deployment was partly driven by its early standardization of reactor and plant design); *see also* Nocito, *supra* note 149, at 187 (noting that non-exclusive licensing could prevent infringement risks from forestalling smart grid standardization); ALLWOOD ET AL., *supra* note 20, at 37–38.

175. Graham & Sichelman, *supra* note 35, at 1071–78 (finding that patents are used for supra-competitive pricing, generating licensing revenue, cross-licensing, or securing investment).

change as arguably the most extreme example — are simply difficult to correctly identify, let alone fully comprehend.[176] Climate change is thus frequently characterized as a "wicked problem."[177] For the same reason, environmental lawyers characterize their area of inquiry as one beleaguered by polycentricity, scientific uncertainty, and multivalence.[178] It is remarkably difficult, and arguably counterproductive, to theorize about climate-related issues without many limitations, caveats, and conditions. Second, the scale of climate change dwarfs all innovation-based responses to societal challenges to date.[179] Significant public and private investment activity is required.[180] This throws into question how to divide up risks and rewards between firms and public actors while the public sector is still a prominent leader behind the early innovation crucial to follow-on advances.[181] Third, the climate emergency is chronic, meaning policies that may have worked for acute emergencies, such as pandemics or research programs for national defense, do not make a blueprint for climate change.[182] To name one difference between the chronic emergency that is climate change and acute emergencies: in acute emergencies, the technologies created need to be adopted by public actors only, whereas innovation for a challenge as great as climate change necessarily relies on adop-

176. TIMOTHY MORTON, HYPEROBJECTS: PHILOSOPHY AND ECOLOGY AFTER THE END OF THE WORLD 48 (2013) (describing the cognitive difficulties in coming to terms with climate change as that which structures human experience, but is too "massively distributed in time and space relative to humans" for its full implications to be comprehended entirely); *see generally* GEORGE MARSHALL, DON'T EVEN THINK ABOUT IT: WHY OUR BRAINS ARE WIRED TO IGNORE CLIMATE CHANGE (2015).

177. This term originated with Horst W.J. Rittel & Melvin M. Webber, *Dilemmas in a General Theory of Planning*, 4 POL'Y SCIS. 155 (1973).

178. Elizabeth Fisher, *Environmental Law as 'Hot' Law*, 25 J. ENV'T L. 347, 351 (2013) (explaining that these characteristics mean that environmental law is tasked with framing problems which are in a constant state of flux and contestation, and it is thus a form of "hot law"); *see also* Michel Callon, *An Essay on Framing and Overflowing: Economic Externalities Revisited by Sociology*, 46 SOCIO. REV. (SPECIAL ISSUE) 244, 261–63 (1998) (on the derivation of "'hot' situations" and "'cold' situations").

179. Innovation and behavioral changes will alter virtually every aspect of economic and social life to reduce their environmental impacts. *See* Frans Berkhout, *Sustainable Innovation Management*, *in* THE OXFORD HANDBOOK OF INNOVATION MANAGEMENT 290, 297–98 (Mark Dodgson et al. eds., 1st ed. 2014) (describing climate change as inciting a "wholesale transformation" in markets to a "reconfiguration of systems of provision that are fundamental to the structure and performance of entire economies").

180. Notably, comparisons have been made between climate change and the circumstances that led to the Manhattan Project, see Richard R. Nelson, *The Moon and the Ghetto Revisited*, 38 SCI. & PUB. POL'Y 681, 688–89 (2011), as well as the space race of the 1960s, *see* MARIANA MAZZUCATO, MISSION ECONOMY: A MOONSHOT GUIDE TO CHANGING CAPITALISM (2021).

181. MARIANA MAZZUCATO, THE ENTREPRENEURIAL STATE: DEBUNKING PUBLIC VS. PRIVATE SECTOR MYTHS (2013) (contending that we need to rethink the role of the state in innovation to alleviate societal challenges that rely on innovation, particularly with regards to the division of the risks and rewards as between public and private actors).

182. With thanks to Professors Robert Burrell and Catherine Kelly for a clear articulation of innovation-based emergencies as being either 'acute' or 'chronic.'

tion by both public and private actors.[183] Additionally, reducing GHGs to net-zero will take decades, making it difficult to extrapolate from the mission-oriented policies behind the Manhattan Project or those which landed a man on the moon. The very goal for green innovation is less clearly defined, requiring a variety of decentralized measures.[184] The stylized facts in Part II give an indication of the sheer complexity of green innovation policy.

One of the main contentions this Note seeks to raise is that the innovation system is a helpful framing device to bracket the innovation policy questions as they pertain to patents. Derived from evolutionary economics, it adopts a behavioral treatment of the evolution of innovative practices over time, including imitation and learning processes.[185] It uses a 'meso' perspective to analyze how firms interact with each other in a broader knowledge infrastructure which includes, *inter alia*, education systems and labor markets.[186] Joseph Stiglitz has advocated use of the innovation system in assessing the comparative benefits of mechanisms such as patents, prizes, or government-funded research.[187] Comparisons can be made across the relevant transaction costs, the nature of the selection and allocation mechanisms, or the source of financing.[188] For instance, it is suggested that prizes are preferable to patents for early innovation because they do not limit access to research.[189]

An innovation system analysis ameliorates some deficiencies of existing theorizing. First, it is conducive to a mixed innovation policy portfolio. It describes how patents, in practice, comprise an ex ante incentive mechanism and an ex post allocation mechanism, the latter being modified, *inter alia*, by particular licensing provisions.[190] Second, it raises more demanding questions on the risk and reward allo-

183. *See, e.g.*, David C. Mowery, *Defense-Related R&D as a Model for "Grand Challenges" Technology Policies*, 41 RSCH. POL'Y 1703, 1703–04 (2012) (explaining why one cannot easily extrapolate from the successes of policies for defense-related research and development for climate-related innovation policy because climate change calls for many, varying technological solutions, and has a particular reliance on technology adoption by private firms which is not comparable to the defense model).

184. *See* Nelson, *supra* note 180, at 689.

185. Richard R. Nelson, Sidney G. Winter & Herbert L. Schuette, *Technical Change in an Evolutionary Model*, 90 Q.J. ECON. 90, 92, 100 (1976); *see also* Joseph E. Stiglitz, *Economic Foundations of Intellectual Property Rights*, 57 DUKE L.J. 1693, 1712–13, 1721 (2008).

186. Bengt-Åke Lundvall, *National Innovation Systems — Analytical Concept and Development Tool*, 14 INDUS. & INNOVATION 95, 102 (2007).

187. *See* Stiglitz, *supra* note 185, at 1721–24.

188. *Id.* at 1721.

189. *See* Robert Burrell & Catherine Kelly, *The COVID-19 Pandemic and the Challenge for Innovation Policy*, 71 N. IR. LEGAL Q. 89, 91–94 (2020).

190. *See* Daniel J. Hemel & Lisa Larrimore Ouellette, *Innovation Policy Pluralism*, 128 YALE L.J. 544, 549–50 (2019) (clarifying that, in contrast to the conventional ex ante and ex post analysis, the patent's incentive and allocation mechanisms can be disaggregated in practice through licensing and other measures).

cation mechanisms of existing innovation systems.[191] Merely noting the availability of public funding, few examine whether green R&D outputs are being patented, or with what implications.[192] The argument has been raised for healthcare innovation that consumers may, in effect, be paying twice for innovation.[193] If public funds finance green technology projects, it begs the question of whether firms ought to be entitled to exclusive patent rights over those inventions.[194] Third, it ensures that patent law reform is anticipated by a comparative evaluation on the suitability of other incentive mechanisms.[195] With climate prizes abounding,[196] there may be a case for restricting patentability over breakthroughs, for instance, in hydrogen power.[197] Fourth, it raises questions on how IP affects innovation policy governance.[198] Situated in a social context, moreover, patent law's impacts on public policy goals such as privacy can be managed.[199] More fundamentally, we might ask not only whether we are making full use of our innovation system, but also to what extent the solutions we are *not* getting come down to the design of our existing innovation system.[200] An IP in isolation approach simply does not advance these considerations.

191. Stiglitz, *supra* note 185, at 1712.

192. *Compare* Sarnoff, *supra* note 94, at 303, *with* Derclaye, *supra* note 94, at 667–69, *and* Xiang, *supra* note 28, 10–11.

193. A recent talk at University College London focused on this issue in the wake of the COVID-19 pandemic, during which pharmaceutical companies are recouping profits several times over the costs of vaccines research, despite the fact that much of this research was state-subsidized, and almost ironically, that purchasers of these vaccines are states. UCL Institute for Innovation and Public Purpose, *Are We Paying Twice for Health Innovation?*, YOUTUBE (May 5, 2021), https://youtu.be/ZgX0laIAaPI [https://perma.cc/TZL3-ALBR].

194. *See* Mariana Mazzucato, *From Market Fixing to Market-Creating: A New Framework for Innovation Policy*, 23 INDUS. & INNOVATION 140, 152–53 (2016) (arguing that where the government is lead risk-taker on early innovation, it can choose to retain intellectual property rights in outputs as return-generating mechanisms); Scotchmer, *supra* note 63, at 40 (arguing that "[p]ermitting patents on government sponsored research rewards successful innovators twice, once through government funding and again through the patents").

195. Stiglitz, *supra* note 185, at 1719–21 (arguing that, notably, prizes are often better alternatives to patents).

196. *See, e.g.*, THE EARTHSHOT PRIZE, https://earthshotprize.org/ [perma.cc/K689-2GQT]; XPRIZE, https://www.xprize.org/ [https://perma.cc/R7N2-86FN]; *Virgin Earth Challenge*, VIRGIN, https://www.virgin.com/about-virgin/virgin-group/news/virgin-earth-challenge [https://perma.cc/LG88-63JT].

197. *See* Nelson, *supra* note 37, at 302 (noting that patents are unsuited to incentivizing basic scientific research).

198. *See* Drahos, *supra* note 12, at 40 (suggesting that the international intellectual framework is liable to promote the activities and "opportunistic behaviour of multinational patent elites" when it comes to climate-friendly technology).

199. Smart grids, for instance, rely on digital records of user or producer personal information, raising issues of privacy law. *See* Kapczynski & Syed, *supra* note 85, at 1958–60.

200. Nelson, *supra* note 6, at 682.

V. CONCLUSION

As innovation-based solutions to social problems grow in importance, patent law will increasingly come under attack. Framing the challenge for a polycentric social problem like climate change requires looking to the broader innovation context to understand where patent law is failing — and where it is not. The suggestion that the patent incentive does not encourage breakthroughs does not necessarily make it a poor tool, but suggests it is not the *appropriate* tool in this instance. On the other hand, it is conceivable that patents are still important, for instance, for technology commercialization and diffusion. One framing device is that of the innovation system. The drive to develop and disseminate a COVID-19 vaccine has already demonstrated powerfully the limits to the prevailing innovation policy behind patent law.[201] There are lessons to be learned from the pandemic in responding to climate change:

> The climate emergency is like the COVID-19 emergency, just in slow motion and much graver. Both involve market failures, externalities, international cooperation, complex science, questions of system resilience, political leadership, and action that hinges on public support. Decisive state interventions are also required to stabilize the climate, by tipping energy and industrial systems towards newer, cleaner, and ultimately cheaper modes of production that become impossible to outcompete.[202]

Climate change, more so than the COVID-19 pandemic, is a present and accelerating crisis: the consequences of inaction become graver with time, and those very same consequences are an accelerant for a whole host of interrelated social problems. Some say a Manhattan Project for climate change is needed, though even the most ambitious policies for innovation to date — notably, those which delivered the hydrogen bomb or COVID-19 vaccines — are perhaps not models for the issues posed by climate change. Developing answers to these difficult questions calls for integrated approaches. It starts with the acknowledgement that it is worth rethinking known weaknesses in

---

201. Rachel E. Sachs, Lisa Larrimore Ouellette, W. Nicholson Price II & Jacob S. Sherkow, *Innovation Law and COVID-19: Promoting Incentives and Access for New Healthcare Technologies*, *in* COVID-19 AND THE LAW: DISRUPTION, IMPACT AND LEGACY (Glenn Cohen et al. eds., forthcoming 2022) (draft at 11).

202. Cameron Hepburn, Brian O'Callaghan, Nicholas Stern, Joseph Stiglitz & Dimitri Zenghelis, *Will COVID-19 Fiscal Recovery Packages Accelerate or Retard Progress on Climate Change?*, 36 OXFORD REV. ECON. POL'Y (SPECIAL ISSUE) S359, S360 (2020).

innovation policy.[203] Doing so may be instrumental to making the patent system fit-for-purpose for green innovation.

203. *See* Burrell & Kelly, *supra* note 189, at 91–94; *see also* Lisa Larrimore Ouellette, *Patent Experimentalism*, 101 VA. L. REV. 65, 68 (2015) (arguing for evidence-based research on the effect of patents on innovation to counteract uniform approaches to patent protection); Hemel & Ouellette, *supra* note 190, at 613 (arguing for nuance in how we construe the impact of patents on innovation and a comparative institutional analysis of differing innovation policy levers).