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EMILY MICHIKO MORRIS

Although scientists have for decades now had the ability to manipulate matter at the atomic level, we have yet to see the nanotechnological revolution that these scientists predicted would follow. Despite the years of effort and billions of dollars that have been invested into research and development thus far, nanotechnology has yielded surprisingly few end-user applications. A number of commentators have blamed this lack of progress on the Bayh-Dole Act and other changes to patent law, arguing that, although these laws are supposed to stimulate technological development, they have in fact had the exact opposite effect when it comes to nanotechnology. Because universities now own too many "upstream" patent rights with the potential to obstruct "downstream" development of usable applications, their argument goes, the Bayh-Dole Act has caused an unnecessary drag on nanotechnology development. This Article shows, however, that contrary to this common criticism, patents on university-based nanotechnology research are most often simply irrelevant.

While nanotechnology applications have been slow to emerge, this Article shows that the latency in development is due not to patents but rather to the fact that nanotechnology is a science-based technology and as such faces various additional hurdles that far outweigh the potential effect of any upstream patenting by universities. Just the inherent technological difficulties alone of working in science-based fields makes development cycles in these fields unavoidably long. To make matter worse, science-based fields typically also face issues with tacit knowledge and the lack of widespread expertise as well as the "valley of death" and the difficulties of attracting investment in intermediate-stage development. Add to this mix constraints due to concerns about public health and safety along with limited access to proprietary materials and equipment and it is not difficult to understand why nanotechnology development has not advanced as quickly as some might have hoped. Thus, while nanotechnology and other science-based technologies may occasionally experience patent-related holdup problems, development in these fields would be more effectively addressed by looking instead at the multitude of other, nonpatent factors that pose well-recognized obstacles in such science-based technologies.

ARTICLE CONTENTS

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EMILY MICHIKO MORRIS*

INTRODUCTION

Once the stuff of science fiction, nanotechnology is now expected to be the next technological revolution.[1] For over thirty years, the United States government has invested several billion dollars into research and development of technologies that exploit the unusual qualities of matter at the atomic level.[2] All of this enthusiasm has yielded thousands of nanotechnology patents[3] but little in the way of revolutionary new products and applications. We have yet to see the brave new world of efficient energy sources and targeted, cell-specific chemotherapy delivery systems that nanotechnology researchers have been working to develop for years, and the self-replicating nanobots we see in Star Trek and other science fiction seem to be nothing more than that—science fiction.[4] "Nanotechnology" has become less of a technological revolution and instead more of buzzword to create hype for otherwise mundane products that have little to do with actual

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[1] Graham Reynolds, *Nanotechnology and the Tragedy of the Anticommons: Towards a Strict Utility Requirement*, 6 U. OTTAWA L. TECH. J. 79, 81 (2009).

[2] Requests for federal funding of nanotechnology research and development totaled almost two-billion dollars in fiscal year 2013 alone. JOHN C. MONICA, NANOTECHNOLOGY LAW § 2:116 (2014); *see also* Ted Sabety, *Nanotechnology Innovation and the Patent Thicket: Which IP Policies Promote Growth?*, 15 ALB. L.J. SCI. & TECH. 477, 504–05 (2005) (noting that venture capital investments are much smaller by comparison); Rachel Lorey Allen, *Venture Capital Investment in Nanotechnology*, JONES DAY, http://www.jonesday.com/practiceperspectives/nanotechnology/venture_capital.html [https://perma.cc/T4G3-R3VY] (last visited Nov. 16, 2016) (similar).

[3] Raj Bawa, *Nanotechnology Patent Proliferation and the Crisis at the U.S. Patent Office*, 17 ALB. L.J. SCI. & TECH. 699, 707 n.26 (2007); Mark A. Lemley, *Patenting Nanotechnology*, 58 STAN. L. REV. 601, 604, 604 n.14 (2005); Siva Vaidhyanathan, *Nanotechnologies and the Law of Patents: A Collision Course*, *in* NANOTECHNOLOGY: RISK, ETHICS AND LAW 225, 227 (Geoffrey Hunt & Michael Mehta eds., 2006).

[4] Lemley, *supra* note 3, at 602; MONICA, *supra* note 2, § 1:10; Douglas Sharrott & Sachin Gupta, *How to Cope with the Expiration of Early Nanotechnology Patents*, 8 NANOTECH. L. & BUS. 159, 160 (2011).

nanotechnological breakthroughs.[5] Any real nanotechnological shift in the way we manufacture goods and the materials we use seems to remain a distant future, stuck in a holding pattern as a perpetually *immature* field, an "emerging science," and a "new technology."[6] Why?

Professor Mark Lemley and a number of others have suggested that the answer to this puzzling question is simple: nanotechnology differs from all of the technologies that came before it.[7] As the first major new technological field after the Bayh-Dole Act[8] and other related statutes and changes to patentability standards,[9] nanotechnology has experienced an unprecedented boom in patenting, particularly on basic research and research tools. What is more, an unprecedented number of these patents are held by universities.[10] Patents on "upstream" research of this nature have the potential to obstruct "downstream" development of usable products and other applications.[11] Lemley and others argue that the Bayh-Dole Act, which now encourages recipients of government research funding to patent the resulting basic research, has caused an anticommons—or a thicket—of patents so dense and overwhelming that it is stunting nanotechnology development, a problem yet further exacerbated by nanotechnology's potentially cross-disciplinary nature.[12] Although patents are supposed to promote technological progress, Bayh-Dole has created simply *too many* patents in nanotechnology.

This Article shows that a "tragedy of the anticommons" characterization

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[5] JOHN C. MILLER ET AL., THE HANDBOOK OF NANOTECHNOLOGY: BUSINESS, POLICY, AND INTELLECTUAL PROPERTY LAW 151–52 (2005); Jue Wang & Philip Shapira, *Partnering with Universities: A Good Choice for Nanotechnology Start-Up Firms?*, 38 SMALL BUS. ECON. 197, 203 (2012), http:/link.springer.com/article/10.1007/s11187-009-9248-9 [https://perma.cc/Z55S-ZLAF].

[6] *E.g.*, Zia Akhtar, *Nanotechnology: Meeting the Challenges of Innovation, Production, and Licensing*, 9 NANOTECH. L. & BUS. 133, 133–34 (2012); Frederick A. Fiedler & Glenn H. Reynolds, *Legal Problems of Nanotechnology: An Overview*, 3 S. CAL. INTERDISC. L.J. 593, 594–95 (1994); Lemley, *supra* note 3, at 605; Frank Murray et al., *Defense Drivers for Nanotechnology Commercialization: Technology, Case Studies, and Legal Issues*, 9 NANOTECH. L. & BUS. 4, 5 (2012). Most commentators agree that the field of nanotechnology has existed since at least the mid-1980s. *See, e.g.*, Francisco Castro, *Legal and Regulatory Concerns Facing Nanotechnology*, 4 CHI.-KENT J. INTELL. PROP. 140, 140 (2004) (citing nanotechnology's "formal existence" to the publication of K. ERIC DREXLER, ENGINES OF CREATION: THE COMING ERA OF NANOTECHNOLOGY (1st ed. 1986)); Reynolds, *supra* note 1, at 87 (same).

[7] Lemley, *supra* note 3, at 605–06.

[8] *See* 35 U.S.C. §§ 200–12 (2000) (incorporating the Bayh-Dole Act's provisions into the Patent Act).

[9] *See infra* text accompanying notes 60–68.

[10] Lemley, *supra* note 3, at 601, 605–06.

[11] *Cf.* Sabety, *supra* note 2, at 481 n.12 (describing "upstream" as "seminal breakthrough inventions" and "downstream" as "follow-on . . . innovations").

[12] Lemley, *supra* note 3, *passim*; *see also* Joel D'Silva, *Pools, Thickets and Open Source Nanotechnology*, 31 EUR. INTELL. PROP. REV. 300, *passim* (2009); Terry K. Tullis, Comment, *Application of the Government License Defense to Federally Funded Nanotechnology Research: The Case for a Limited Patent Compulsory Licensing Regime*, 53 U.C.L.A. L. REV. 279, *passim* (2005); Bawa, *supra* note 3, *passim*; Reynolds, *supra* note 1, at 81–85, 96–98.

of development in nanotechnology is too simple. Lemley is correct that nanotechnology development has been slow, but not for the reasons he suggests. In fact, for many, if not most, aspects of nanotechnology development, patents on university-based research are simply *irrelevant*. This Article shows that in nascent but complex fields like nanotechnology, technological and economic uncertainty, long development cycles, tacit knowledge, lack of funding, and even regulatory and safety issues are likely to be much more significant and rate-limiting than patents are. In this way, nanotechnology is not nearly as unique as Lemley suggests; nanotechnology's developmental difficulties are the same, well-known difficulties that other science-based technologies face. This is not to say that all nanotechnology patents are irrelevant or that an "anticommons" could never interfere in the development of nanotechnology applications. The point here is simply that patenting of basic research, whether by universities or any other entities, is not the problem. Those concerned about the lack of progress in nanotechnology would be better served to look at the multitude of other factors, such as lack of funding, limited access to expertise and materials, long development cycles, and public-safety concerns, that are well known to slow research-intensive fields such as nanotechnology and biotechnology.[13]

The following discussion examines the characteristics of science-based technologies and explains why patents likely play a minimal role, at least at this point, in nanotechnology development, particularly with regard to university patenting on upstream technology under the Bayh-Dole Act and its related statutes. Section I provides a general description of nanotechnology, its origins, and its potentially cross-disciplinary effect. Section II then briefly describes the concern, as put forth by Professor Lemley and other commentators, that high levels of university patenting on basic research has created and continues to create an anticommons that is stifling nanotechnology development. Section III provides a different story, however. First, as in biotechnology, anticommons in nanotechnology are probably more feared than real at this stage. Second, and more importantly, Section III shows why it is more likely that development of early-stage university research in nanotechnology is suffering not from problems caused by patenting under Bayh-Dole but from many of the same nonpatent problems that have always affected science-based technologies. This latter group of problems—including tacit knowledge,[14] the valley of death,[15] safety concerns,[16] and more[17]—are currently much larger obstacles than any

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[13] *See infra* Section III.B.

[14] For a discussion of tacit knowledge, see *infra* Section III.B.4.

[15] For a discussion of the valley of death, see *infra* Section III.B.2.

[16] For a discussion of safety concerns, see *infra* Section III.B.6.

[17] *Infra* Section III.B.

that patents might pose at this point in nanotechnology's development.

I. NANOTECHNOLOGY: THE BASICS

Named after the nanometer, or one billionth of a meter,[18] nanotechnology is the study of the unique physical and chemical characteristics of matter at the sub-microscopic level.[19] At this scale, substances often display different physical and chemical properties because the high surface-area-to-volume ratio allows otherwise very weak quantum forces to dominate over other physical forces.[20] This difference causes the melting points, electrical conductivity, reflectivity, tensile strength, and magnetic and optical properties of matter to vary in surprising ways from their macroscopic forms.[21] By leveraging these differences, scientists have been able to create some amazing new materials. Researchers have now been successful in synthesizing miraculously light, yet strong materials, such as carbon nanotubes that are one-sixth the weight but one hundred times the strength of steel,[22] carbon fullerenes ("buckyballs") that can be used for targeted drug delivery to individual cells,[23] and semiconductor nanocrystals ("quantum dots") small enough to map DNA sequences.[24] Bar-coded nanowires can be used to create nanoscale sensors that can identify biowarfare pathogens at sensitivity levels never before seen.[25] The branched structure of dendrimers can be used as drug-release mechanisms that simultaneously monitor body vitals to regulate dosages.[26] Nanotechnology is expected to revolutionize a wide array of industries, including medicine,

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[18] As a point of reference, a single helium atom is approximately one tenth of a nanometer in diameter, and a ribosome, a very small intracellular organelle, is approximately twenty nanometers in diameter. D'Silva, *supra* note 12, at 300.

[19] *Id.*; Bawa, *supra* note 3, at 704; Amit Makker, Note, *The Nanotechnology Patent Thicket and the Path to Commercialization*, 84 S. CAL. L. REV. 1163, 1164 (2011).

[20] SOCIETAL IMPLICATIONS OF NANOSCIENCE AND NANOTECHNOLOGY: NAT'L SCI. FDN. NSET WORKSHOP REPORT *passim* (Mihail C. Roco & William Sim Bainbridge eds., 2001) [hereinafter SOCIETAL IMPLICATIONS], http://www.wtec.org/loyola/nano/NSET.Societal.Implications/nanosi.pdf [https://perma.cc/4KKY-U3CK]; Bawa, *supra* note 3, at 705; Gunter Festel et al., *Importance and Best Practice of Early Stage Nanotechnology Investments*, 7 NANOTECH. L. & BUS. 50, 50 (2010); Siddarth Khanijou, *Patent Inequity?: Rethinking the Application of Strict Liability to Patent Law in the Nanotechnology Era*, 12 J. TECH. L. & POL'Y 179, 187 (2007).

[21] SOCIETAL IMPLICATIONS, *supra* note 20; Bawa, *supra* note 3, at 705; Festel et al., *supra* note 20, at 50; Khanijou, *supra* note 20, at 187.

[22] William J. Simmons, *Nanotechnology as a Nascent Technological Model for Immediate Substantive United States and Japan Patent Law Harmonization*, 17 ALB. L.J. SCI. & TECH. 753, 774 (2007).

[23] Behfar Bastani & Dennis Fernandez, *Intellectual Property Rights in Nanotechnology*, INTELL. PROP. TODAY 36, at text accompanying note 19 (Aug. 2002), http://www.iploft.com/Nanotechnology.pdf [https://perma.cc/MWB7-WVLU].

[24] David S. Almeling, Note, *Patenting Nanotechnology: Problems with the Utility Requirement*, 2004 STAN. TECH. L. REV. 1, P8 (2004).

[25] Murray et al., *supra* note 6, at 14.

[26] *Id.* at 15.

energy, textiles, and electronics, leading many to hail nanotechnology as "a key technology for economic development in the twenty-first century"[27] and to compare nanotechnology to the steam engine, transistor, and the Internet in its potential effect on society.[28]

Like many pioneering technologies, nanotechnology originated largely through basic research performed by government-funded universities and federal laboratories. Governments around the world have invested billions of dollars in nanotechnology research, with private industry and investors quickly following suit.[29] In the United States, for example, both federal and state government support for nanotechnology has expanded geometrically over the last two decades.[30] By 2001, Congress and President Clinton had established the National Nanotechnology Initiative (NNI) to promote and coordinate nanotechnology research among several federal agencies, including the Department of Defense, the Department of Energy, the National Institutes of Health, and the Department of Justice;[31] by 2017 the NNI's total investment in nanotechnology will exceed $24 billion.[32] Developed countries around the world have made similar investments in anticipation of the "next industrial revolution."[33]

The field continues to be very much in its infancy, however, and the value of nanotechnology innovations remains highly speculative.[34] Much of nanotechnology is still in the early research stages and has yet to be developed into marketable products.[35] According to the Project on Emerging

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[27] Maryam Ahmadi & Leila Ahmadi, *Intellectual Property Rights of Bionanotechnology in Related International Documents*, 8 NANOTECH. L. & BUS. 289, 289 (2011).

[28] *E.g.*, Neal Lane & Thomas Kalil, *The National Nanotechnology Initiative: Present at the Creation*, 21 ISSUES IN SCI. & TECH. (2005), http://issues.org/21-4/lane/ [https://perma.cc/8YES-AJB4].

[29] Bawa, *supra* note 3, at 701.

[30] Simmons, *supra* note 22, at 775–76.

[31] Jordan Paradise, *Reassessing Safety for Nanotechnology Combination Products: What Do Biosimilars Add to Regulatory Challenges for the FDA?*, 56 ST. LOUIS L.J. 465, 474 (2012).

[32] NAT'L SCI. & TECH. COUNCIL COMM. ON TECH. & THE SUBCOMM. ON NANOSCALE SCI., ENG'G, & TECH., THE NATIONAL NANOTECHNOLOGY INITIATIVE: SUPPLEMENT TO THE PRESIDENT'S 2017 BUDGET 3 (Mar. 2016), https://www.whitehouse.gov/sites/default/files/microsites/ostp/nni_fy17_budget_supplement.pdf [https://perma.cc/2GXB-DXMK]. This author has been unable to find a reliable estimate of what proportion of the U.S. government's overall R&D spending is devoted to nanotechnology, however, because of the interdisciplinary nature of nanotechnology and the consequent difficulty of identifying nanotechnology funding separately from funding in other fields.

[33] *See* Allen, *supra* note 2 (noting China, South Korea, and the E.U.'s nanotechnology investments); Simmons, *supra* note 22, at 777–78 (noting Japan's multibillion dollar investments in nanotech); *see also* NAT'L SCI. & TECH. COUNCIL, COMM. ON TECH. & THE SUBCOMM. ON NANOSCALE SCI., ENG'G, & TECH., NATIONAL NANOTECHNOLOGY INITIATIVE: RESEARCH AND DEVELOPMENT SUPPORTING THE NEXT INDUSTRIAL REVOLUTION, SUPPLEMENT TO THE PRESIDENT'S 2004 BUDGET 1 (2003), http://www.nano.gov/sites/default/files/pub_resource/nni04_budget_supplement.pdf [https://perma.cc/U3KD-456H] (referring to nanotech as an "industrial revolution"). For more detail on private-industry investment in nanotechnology R&D, on the other hand, see *infra* text accompanying notes 257–62.

[34] Lane & Kalil, *supra* note 28.

[35] Lemley, *supra* note 3, at 604.

Nanotechnologies' survey, 1,628 consumer products on the market contained nanomaterials as of 2013,[36] and many products contain only small amounts of nanotechnology.[37] Most of these products represent incremental improvements to existing technologies, such as stain-resistant nanocoatings, high-tech tennis rackets, ski wax, and sunscreen.[38] Yet other products bear the "nano" name more to create buzz than to give an accurate description of the underlying product.[39] The radical new "disruptive" technologies that many expected nanotechnology to produce have yet to appear, however,[40] leading many to note that, despite the large sums of money invested in the field thus far, surprisingly few groundbreaking nanotechnology products have reached the market.[41] The lack of current commercial value notwithstanding, a surprisingly large number of patents on basic nanotechnology research have been filed by both universities and private firms. In fact, critics claim that very few of the nanotechnology inventions created thus far have not been patented; patents have issued on carbon nanotubes, quantum dots, nanowires, dendrimers, atomic-force microscopes, and many other basic tools and materials.[42]

At first glance, it is not surprising that everyone wants to get in early on the patent "gold rush" of the next major industrial revolution. Closer inspection reveals that basic research patents in nanotechnology are something of an oddity. Patents are popularly conceived of as a mechanism for incentivizing investment in technological research and development (R&D) by helping investors appropriate returns on their investments *ex post* by charging for access to the patented inventions.[43] Because the vast majority of nanotechnology research conducted thus far has been funded through the federal government,[44] patent protection would seem unnecessary; technologies that have been funded *ex ante* through

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[36] *Inventory Finds Increase in Consumer Products Containing Nanoscale Materials*, PROJECT ON EMERGING NANOTECHNOLOGIES (Oct. 28, 2013), http://www.nanotechproject.org/news/archive/9242/ [https://perma.cc/2ZAP-UQHY].

[37] Josh Wolfe, *Blue Chips Stack Up on Nanotechnology*, FORBES (Oct. 24, 2005, 1:00 PM), http://www.forbes.com/2005/10/24/motorola-lucent-hp-nano-ppg-cz_jw_1024soapbox_inl.html.

[38] Akhtar, *supra* note 6, at 134; Andrew Wasson, *Protecting the Next Small Thing: Nanotechnology and the Reverse Doctrine of Equivalents*, 2004 DUKE L. & TECH. REV. 10, 10 (2004).

[39] MILLER ET AL., *supra* note 5, at 151–52.

[40] Allen, *supra* note 2.

[41] *E.g.*, Sean O'Neill et al., *Broad Claiming in Nanotechnology Patents: Is Litigation Inevitable?*, 4 NANOTECH. L. & BUS. 29, 31 (2007) (noting the lack of nanotechnology products in the marketplace); Lemley, *supra* note 3, at 604, 623 (stating that nanotechnology "has so far produced few actual products"); *see also* Dennis S. Karjala, *Protecting Innovation in Computer Software, Biotechnology, and Nanotechnology*, 16 VA. J.L. & TECH. 42, 46 (2011) (arguing that few nanotech products on the market truly represent the unique characteristics of nanotechnology).

[42] Lemley, *supra* note 3, at 613–14; Reynolds, *supra* note 1, at 86.

[43] Rebecca S. Eisenberg, *A Technology Policy Perspective on the NIH Gene Patenting Controversy*, 55 U. PITT. L. REV. 633, 648 (1994).

[44] Sabety, *supra* note 2, at 504–05.

government or other monies do not require the incentive of patent exclusivity.[45] Patenting on research already funded by the government also violates the "reward theory" of patenting, by which patents serve primarily to afford the opportunity to appropriate private returns on investments in invention and innovation.[46] Allowing patents on inventions that have been funded through government-collected taxpayer funds also effectively charges the public twice.[47]

Indeed, the type of research and development that governments are most likely to fund *ex ante* are exactly those that the prospect of patent exclusivity is unable to incentivize. Basic—or, "pure"—research, particularly in complex and unpredictable fields such as biotechnology and nanotechnology, is often thought to be too uncertain and distant in value to be attractive as investments to private firms.[48] Even when protected by patents, the expected value of such basic research will be less than its expected cost, and private firms will invest their resources in areas with more certain returns.[49] Because basic scientific and technological research has great public value, however, governments step in and use public funds to subsidize research that otherwise might never be funded.[50]

In the wake of the Bayh-Dole and the Stevenson-Wydler Acts, however, university patenting on government-funded and other research increased dramatically.[51] Levels of university patenting increased by more than eightfold between the late 1970s and the 1990s, with universities spending almost six times as much on patenting in 2004 as they did in 1991, and this upward trend continues to this day.[52] How much of this increase in

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[45] Rebecca S. Eisenberg, *Public Research and Private Development: Patents and Technology Transfer in Government-Sponsored Research*, 82 VA. L. REV. 1663, 1666–67 (1996); Arti K. Rai & Rebecca S. Eisenberg, *The Public Domain: Bayh-Dole Reform and the Progress of Biomedicine*, 66 LAW & CONTEMP. PROB. 289, 300–01 (2003).

[46] Donald G. McFetridge & Douglas A. Smith, Comment, *Patents, Prospects and Economic Surplus: A Comment*, 23 J.L. & ECON. 197, 198 (1980).

[47] Eisenberg, *supra* note 45, at 1666; Michael S. Mireles, *Adoption of the Bayh-Dole Act in Developed Countries: Added Pressure for a Broad Research Exemption in the United States?*, 59 ME. L. REV. 259, 261 (2007); Jacob H. Rooksby, *University Initiation of Patent Infringement Litigation*, 10 J. MARSHALL REV. INTELL. PROP. L. 623, 631 (2011).

[48] Suzanne Scotchmer & Stephen M. Maurer, *Innovation Today: Private-Public Partnership*, *in* SUZANNE SCOTCHMER, INNOVATION AND INCENTIVES 227, 230 (2004); Eisenberg, *supra* note 45, at 1695–96.

[49] GEORGE S. FORD ET AL., PHOENIX CENTER FOR ADVANCED LEGAL & ECONOMIC PUBLIC POLICY STUDIES, A VALLEY OF DEATH IN THE INNOVATION SEQUENCE: AN ECONOMIC INVESTIGATION 11 (2007); Brett Frischmann, *Innovation and Institutions: Rethinking the Economics of U.S. Science and Technology Policy*, 24 VT. L. REV. 347, 352 (2000).

[50] Scotchmer & Maurer, *supra* note 48, at 244, 246.

[51] David E. Adelman, *A Fallacy of the Commons in Biotech Patent Policy*, 20 BERKELEY TECH. L.J. 985, 989 (2005); Mireles, *supra* note 47, at 264.

[52] ASS'N UNIV. TECH. MANAGERS, AUTM U.S. LICENSING SURVEY: FY 2014 (2016); Richard R. Nelson, *Observations on the Post-Bayh-Dole Rise of Patenting at American Universities*, 26 J. TECH.

university-based, upstream patenting is actually due to changes in the law is unclear. Much of the increase in university-centered biomedical research patenting occurred simultaneously with an increase in government funding for such research,[53] and the high proportion of university-owned patents that we see in nanotechnology may likewise be due to the fact that government funding continues to be one of the main drivers of research in the area.

Regardless of the reasons for the increase in university patenting of upstream research, however, a number of commentators have expressed grave doubts about the wisdom of such patenting patterns. Commentators like Professor Lemley and others argue that the large volume of upstream, university-owned patenting makes nanotechnology development uniquely ripe for anticommons and other holdup problems.[54] But are patents truly the problem? Or is development in a science-based technology like nanotechnology unavoidably slow for a variety of reasons that have little to do with patenting at this point in time? The following two sections address each of these explanations to show that upstream patents held by universities and other government funding recipients likely have little to do with the slow rate of nanotechnology development thus far.

II. LEMLEY'S STORY: THE TRAGEDY OF THE ANTICOMMONS

Lemley and other commentators on nanotechnology development argue that a combination of three patent-related factors have paradoxically slowed progress in nanotechnology. First, liberalization of both patentable subject matter restrictions and patentable utility standards in the 1980s and 1990s paved the way for patenting on technology much earlier in the research and development process.[55] Second, because nanotechnology is a uniquely cross-disciplinary field, the increase in upstream research patents may have a particularly broad effect on downstream development.[56] Third, enactment of the Bayh-Dole Act in 1980 encouraged patenting of government-funded research, resulting not only in a marked surge in upstream patenting but also a new class of patent holders that lack either the expertise or the orientation to license their patent effectively.[57] The combined effect of these three changes in patenting patterns is to create an anticommons, or overparcelization of patent rights, that inflates transaction costs and hinders

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TRANSFER 13, 13 (2001); Kristen Osenga, *Rembrandts in the Research Lab: Why Universities Should Take a Lesson from Big Business to Increase Innovation*, 59 ME. L. REV. 407, 419 (2007).

[53] David C. Mowery & Arvids A. Ziedonis, *Academic Patents and Materials Transfer Agreements: Substitutes or Complements?*, 32 J. TECH. TRANSFER 157, 158 (2007). *But see* Eisenberg, *supra* note 45, at 1702–05 (questioning whether pre-Bayh-Dole government patents were actually underutilized).

[54] Lemley, *supra* note 3, at 620.

[55] *Id.* at 613.

[56] *Id.* at 614.

[57] *Id.* at 617.

downstream development.[58] And as the first major technological field to emerge since these changes, critics argue, nanotechnology development may now suffer from the same tragedy of the anticommons and other holdup problems that these changes may have caused in biotechnology as well.[59]

First, many commentators assert that nanotechnology has experienced a high level of patenting on upstream, basic research due to relaxation of both patentable subject matter and patentable utility standards, both of which occurred around the same time in the early 1980s.[60] According to the critics, changes in the patentability of both basic research and federally-funded research now allow universities to patent more of their nanotechnology research and to patent it earlier in the research process than ever before. For example, naturally occurring products, laws of nature, and abstract ideas have long been held to be unpatentable subject matter.[61] The Supreme Court's 1980 decision in *Diamond v. Chakrabarty*[62] is widely thought to have relaxed these restrictions, however, by lowering the bar for what can be deemed a patentable modification or "application" of a naturally occurring product or law of nature.[63] As a result, basic nanotechnology research on previously unrecognized characteristics of substances at the nanoscopic level have become more likely to be patentable with only minor modifications over the substances' naturally occurring forms.[64] Similar case law on the utility requirement, such as *In re Brana*,[65] in addition to revisions to the United States Patent and Trademark Office's (USPTO's) 1995 Utility Guidelines, also have loosened the utility requirements for so-called research tools or research intermediates.[66] As a result, much basic, upstream research has now become patentable even though it typically requires a good deal of further downstream investment and development to be incorporated

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[58] *Id.* at 618.

[59] *See* Michael A. Heller & Rebecca S. Eisenberg, *Can Patents Deter Innovation? The Anticommons in Biomedical Research*, 280 SCI. 698, 698 (1998) (discussing the tragedy of the anticommons in scientific research in biotechnology); Eisenberg, *supra* note 43, at 640 (same).

[60] *E.g.*, Lemley, *supra* note 3, at 613, 628; Simmons, *supra* note 22, at 783–85.

[61] Diamond v. Chakrabarty, 447 U.S. 303, 309 (1980); *see also* Mark Williamson & James Carpenter, *Traversing Art Rejections in Nanotechnology Patent Applications—No Small Task*, 7 NANOTECH. L. & BUS. 131, 137–38 n.40 (2010) (citing cases).

[62] 447 U.S. at 303.

[63] *Id.* at at 309 (declining to hold genetically modified bacteria to be unpatentable subject matter simply because they are living organisms and because they derive from products of nature); Symposium, G. Nagesh Rao, Note, *Nanotechnology: A Look into the Future of Arising Legal Dilemmas*, 17 ALB. L.J. SCI. & TECH. 835, 848 (2007); Tullis, *supra* note 12, at 287.

[64] Simmons, *supra* note 22, at 785; Nicholas M. Zovko, Comment, *Nanotechnology and the Experimental Use Defense to Patent Infringement*, 37 MCGEORGE L. REV. 129, 141,141 n.130 (2006).

[65] 51 F.3d 1560, 1568 (Fed. Cir. 1995) (holding that patents do not have to reach FDA approval in order to meet the utility requirement).

[66] Utility Examination Guidelines, 60 Fed. Reg. 36, 263 (July 14, 1995).

into usable end products with real-world utility.[67] The creation of the United States Court of Appeals for Federal Circuit in 1982 and its perceived pro-patent stance are alleged to have softened the various patentability requirements, further intensifying upstream patenting in new fields such as nanotechnology.[68]

The overall effect of these and other changes in the patent system has led to early-stage research patents on "incomplete" inventions that have little in the way of immediate application. By patenting incomplete inventions, researchers leave much of the development work to others while reserving to themselves the ability to charge downstream royalties or licensing fees, effectively allowing upstream patentees to extract rents from downstream developers. To make matters worse, the boundaries of upstream research patents are also thought to be more vague. Because upstream research itself tends to be more conceptual and abstract, it has the potential to cover broad ranges of downstream developments, further enhancing its preemptive effects.[69]

In a related vein, many commentators complain that nanotechnology suffers from not only greater upstream patenting but also poorer patent quality.[70] In addition to common criticisms about the USPTO's high application backlog, high examiner turnover rates, and so on,[71] any new field such as nanotechnology presents obvious difficulties for the USPTO. New technologies, particularly complex ones like nanotechnology, pose steep learning curves for USPTO examiners, few of whom will have the necessary expertise for evaluating nanotechnology patent applications.[72] New technologies obviously also lack the kind of robust prior art that exists in more established fields, making it more challenging to identify inventions that fail to meet the novelty or nonobviousness requirements.[73] The fact that many nanotechnological details are easily maintained as trade secrets means that patenting likely does not reflect the total level of nanotechnology innovation and, more importantly, does not adequately reflect the existing

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[67] David E. Adelman & Kathryn L. DeAngelis, *Patent Metrics: The Mismeasure of Innovation in the Biotech Patent Debate*, 85 TEX. L. REV. 1677, 1689–90 (2007); Reynolds, *supra* note 1, at 105.

[68] *E.g.*, Sabety, *supra* note 2, at 488 n.47; *see also* Dov Greenbaum, *Academia to Industry Technology Transfer: An Alternative to the Bayh-Dole System for Both Developed and Developing Nations*, 19 FORDHAM INTELL. PROP. MEDIA & ENT. L.J. 311, 349 (2009) (noting that the Federal Circuit has been "largely perceived as propatent").

[69] Robert P. Merges & Richard R. Nelson, *On the Complex Economics of Patent Scope*, 90 COLUM. L. REV. 839, 884 (1990); Arti K. Rai, *Fostering Cumulative Innovation in the Biopharmaceutical Industry: The Role of Patents and Antitrust*, 16 Berkeley Tech. L.J. 813, 839–40 (2001).

[70] *E.g.*, Bawa, *supra* note 3, at 717–18.

[71] *Id.* at 724–27.

[72] Carl Shapiro, *Navigating the Patent Thicket: Cross Licenses, Patent Pools, and Standard Setting*, 1 INNOVATION POL'Y & ECON. 119, 121 (2001); Heller & Eisenberg, *supra* note 59, at 699.

[73] Akhtar, *supra* note 6, at 138; Bawa, *supra* note 3, at 707–09.

level of applicable prior art in the field.[74]

Moreover, even standardizing terminology can present challenges for new technologies. The USPTO did not have a separate nanotech classification until 2004, when it first established Class 977 for patent applications in this field, and even then, the 977 category includes only inventions that exploit those phenomena occurring at one hundred nanometers or less.[75] Because experts in nanotechnology argue that characteristics occurring at up to three hundred nanometers in size should also qualify as nanotechnology for regulatory purposes,[76] 977's current parameters may be too narrow to include all relevant nanotechnology applications and prior art, particularly with regard to nanomedicine and nanobiotechnology, which often lie outside of 977's one hundred nanometer size limit.[77] And with high patenting levels and steep learning curves come inevitable delays in examining and issuing patents; the backlog of nanotech patent applications and their average pendency have both increased over the years.[78] The uncertainty caused by long patent pendencies can deter downstream developers from entering a field for fear of infringing yet-unissued patents.[79]

A second fact that concerns many commentators is nanotechnology's cross-disciplinary nature, a characteristic that may be unique to nanotechnology. Nanotechnology is unusual in that it is defined solely by size;[80] the exact size limits on what constitutes nanotechnology are in dispute,[81] but any phenomenon that occurs at the nanoscopic level could be argued to qualify as nanotechnology. Given the breadth of this definition, nanotechnology has the potential to revolutionize any number of fields, including biotechnology, electronics, energy, medicine, and materials sciences.[82] Nanotech is thus more size-specific than discipline-specific, which creates some additional issues not seen in most fields. Relevant prior

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[74] Lemley, *supra* note 3, at 617.

[75] U.S. PATENT & TRADEMARK OFFICE, CLASS 977 NANOTECHNOLOGY CROSS-REFERENCE ART COLLECTION, http://www.uspto.gov/patents/resources/classification/class_977_nanotechnology_cross-ref_art_collection.jsp [https://perma.cc/SBQ3-G7RE] (last visited Nov. 16, 2016); *see also* Bawa, *supra* note 3, at 706–07 (discussing the USPTO's decision to establish the Class 977 category).

[76] *E.g.*, FRIENDS OF THE EARTH, OUT OF THE LABORATORY AND ON TO OUR PLATES: NANOTECHNOLOGY IN FOOD & AGRICULTURE 3 (2008), http://www.foe.org/system/storage/877/b5/4/547/Nanotechnology_in_food_and_agriculture_-_web_resolution.pdf [https://perma.cc/2ZY2-W2U2]; Policy Memorandum from Miles V. McEvoy, Deputy Adm'r, U.S. Dep't of Agric., to Stakeholders & Other Interested Parties 1 (Mar. 24, 2015), https://www.ams.usda.gov/sites/default/files/media/NOP-PM-15-2-Nanotechnology.pdf [https://perma.cc/87N8-W8ES].

[77] Bawa, *supra* note 3, at 707.

[78] Raj Bawa, *Patents and Nanomedicine*, 2 NANOMEDICINE 351, 358 (2007).

[79] Heller & Eisenberg, *supra* note 59, at 699; Shapiro, *supra* note 72, at 121.

[80] Bawa, *supra* note 3, at 704.

[81] *Id.*

[82] Lemley, *supra* note 3, at 614.

art becomes more difficult to identify and the appropriate skill level by which to measure patentability becomes more difficult to define.[83] More importantly, nanotechnology's cross-disciplinarity multiplies its potential applications, giving patents in nanotechnology unusually broad effects in many different areas of development.[84] Those who work in downstream nanotech development may need to negotiate licensing from patent holders outside of their own fields and often may be caught infringing patents from fields well outside of what they might reasonably have been expected to review.[85]

The third factor on which Professor Lemley and others predicate their nanotechnology anticommons argument is the Bayh-Dole Act.[86] Before Bayh-Dole took effect, universities and other government-funding recipients had frequently been unable to patent their research, as government agencies sometimes would not allow retention of intellectual property rights on research funded through government grants.[87] The Bayh-Dole Act specifically changed these policies, not only to allow patenting but in fact to promote patent ownership by the recipients of federal funds. Specifically, the Bayh-Dole Act (formally, the Patent and Trademark Law Amendments Act of 1980) set a policy for all federal agencies funding technological research to encourage small businesses and nonprofit organizations such as universities to retain title to their research by filing for patents on it.[88] The somewhat controversial justification for this change was to address the perceived underutilization of government-funded research and to attract private investment in developing and commercializing such research.[89] The post-Bayh-Dole era saw a marked increase in patenting on government-funded research in not only nanotechnology but also other research fields, particularly biotechnology.[90]

One particular twist that Bayh-Dole adds to the mix, moreover, is the concomitant growth in universities as patentees. Bayh-Dole has increased university patenting by about sixteen fold,[91] with estimates putting

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[83] Williamson & Carpenter, *supra* note 61, at 139–40.

[84] Lemley, *supra* note 3, at 614–15.

[85] *Id.*

[86] Adelman, *supra* note 51, at 989.

[87] Sabety, *supra* note 2, at 484–85.

[88] 35 U.S.C. § 202 (2012); *see* Eisenberg, *supra* note 45; Peter Lee, *Transcending the Tacit Dimension: Patents, Relationships, and Organizational Integration in Technology Transfer*, 100 CALIF. L. REV. 1503 (2012); Mireles, *supra* note 47, at 260.

[89] Wei-Lin Wang, *A Critical Study on the Cooperative Research and Development Agreements of U.S. Federal Laboratories: Technology Commercialization and the Public Interest*, 9 NANOTECH. L. & BUS. 50, 53 (2012); Eisenberg, *supra* note 45, at 1669, 1680–82; Sabety, *supra* note 2, at 487–88.

[90] David C. Mowery, *The Bayh-Dole Act and High Technology Entrepreneurship in U.S. Universities: Chicken, Egg, or Something Else?*, *in* 16 ADVANCES IN THE STUDY OF ENTREPRENEURSHIP, INNOVATION & ECONOMIC GROWTH: UNIVERSITY ENTREPRENEURSHIP AND TECHNOLOGY TRANSFER 39, 51 (Gary D. Libecap ed., 2005).

[91] Bawa, *supra* note 3, at 722, 733–34; Lemley, *supra* note 3, at 615–16.

university patenting at about 12% of all nanotechnology patenting and 20.2% of all biomedical nanotech patenting, levels far exceeding university patenting of approximately 1% in other technologies.[92] Universities do not and cannot further commercialize their own research, however, and this uncoupling between invention and commercialization means that universities and private industry must incur the costs of finding and transacting with one another in order for research to be developed into usable end products.[93]

As a result, patent-licensing negotiations after Bayh-Dole now more frequently involve unwonted partners in the form of academically oriented universities transacting with commercially oriented firms. The transactions necessary to develop research-based technologies have become not only more numerous—because patents now exist where they had not before—but also more complicated, because private industry must now negotiate with universities in ways that they had not before. Universities are still disinclined to view themselves as commercial entities, moreover,[94] and even university technology transfer offices (TTOs) do not have the market-based approaches that private commercial entities do.[95] Almost thirty-five years after Bayh-Dole was enacted, universities are still unaccustomed to the commercial world and lack the experience and expertise necessary for patent licensing.[96] Universities also have very different internal authority structures than do more commercial laboratories, and universities serve multiple different constituencies whose often differing goals and agendas often prolong licensing negotiations.[97]

According to Professor Lemley and other critics, the combination of lowered patentability standards, cross-disciplinarity, and increases in university patenting created a perfect storm of nanotechnology patents that

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[92] Lemley, *supra* note 3, at 615–16; Murray et al., *supra* note 6, at 31.

[93] David Blumenthal et al., *Relationships Between Academic Institutions and Industry in the Life Sciences–An Industry Survey*, 334 NEW ENG. J. MED. 368, 370 (1996); Osenga, *supra* note 52, at 421.

[94] Osenga, *supra* note 52, at 421.

[95] *See* Riccardo Fini & Nicola Lacetera, *Different Yokes for Different Folks: Individual Preferences, Institutional Logics, and the Commercialization of Academic Research*, *in* 21 ADVANCES IN THE STUDY OF ENTREPRENEURSHIP, INNOVATION AND ECONOMIC GROWTH: SPANNING BOUNDARIES AND DISCIPLINES: UNIVERSITY TECHNOLOGY COMMERCIALIZATION IN THE IDEA AGE 1, *passim* (2010); Nicholas S. Argyres & Julia Porter Liebeskind, *Privatizing the Intellectual Commons: Universities and the Commercialization of Biotechnology*, 35 J. ECON. BEHAV. & ORG. 427, 444 (1998).

[96] Celestine Chukumba & Richard Jensen, *University, Invention, Entrepreneurship, and Start-Ups* 13, 18–19 (Nat'l Bureau of Econ. Research, Working Paper No. 11475, 2005), http://www.nber.org/papers/w11475 [https://perma.cc/Q4NX-298Y]; Lay Leng Tan, *Generating Dollars from Nanotechnology*, INNOVATION: THE SING. MAG. OF RES., TECH. & EDUC., http://www.innovationmagazine.com/innovation/volumes/v4n3/features4 [https://perma.cc/GVY2-L3YS] (last visited Nov. 16, 2016); Interview with Marie Kerbeshian, Vice President of Tech. Commercialization, Ind. U. Research & Tech. Corp. (Mar. 5, 2015).

[97] Richard Jensen & Marie Thursby, *Proofs and Prototypes for Sale: The Licensing of University Inventions*, 91 AMER. ECON. REV. 240, 244 (2001); Interview with Kerbeshian, *supra* note 96; *see also* Blumenthal et al., *supra* note 93, at 370 (reporting university bureaucracy and regulations as the most frequent obstacle to life science companies forming research relationships with universities).

are not just numerous but also broad, overlapping, and fragmented in ownership.[98] Extrapolating from Michael Heller and Rebecca Eisenberg's famous article on the tragedy of the anticommons in biomedical research, Lemley posits that the explosion of university-owned upstream research patents poses an even greater risk of an anticommons in nanotechnology as well.[99] Anticommons and other holdup problems occur when rights to a particular piece of property are distributed among too many owners, resulting in decreased use of those property rights because of the difficulties of bringing all the rights holders to agreement on how to use their collective property.[100] In the case of technology, "overparcelization" of patent property rights may similarly cause underdevelopment of a given technology.[101] In some cases, a patent may cover a component used only in combination with one or more complementary components that themselves may be subject to separate patent rights, requiring horizontal patent coordination to be used in a productive way.[102] In other cases upstream and downstream patent rights cover "cumulative" technologies, in which separate patented technologies must be vertically coordinated in order to create a single product or process.[103] The need for horizontal or vertical patent coordination could be particularly likely in nanotechnology given that so many basic nanotechnology tools and nanomaterials have been patented.[104] Another source of holdup problems are patent thickets, in which patent rights are particularly dense because patents overlap with one another in scope.[105] This latter type of holdup problem is also thought to pose a particular risk to nanotechnology development, where large numbers of potentially overlapping patents cover multiple aspects and versions of materials like carbon nanotubes and semiconducting nanocrystals.[106] Because patents on upstream nanotechnology already number in the thousands, with the rate of

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[98] Reynolds, *supra* note 1, at 83 (citing *Nanotechnology Gold Rush Yields Crowded, Entangled Patents*, LUX RESEARCH INC. (Apr. 21, 2005), http://www.prnewswire.com/news-releases/nanotechnology-gold-rush-yields-crowded-entangled-patents-54373177.html [https://perma.cc/G8CL-GZ6W].

[99] *Id.* at 97.

[100] Heller & Eisenberg, *supra* note 59, at 698.

[101] *Id*.

[102] Mark A. Lemley, *The Myth of the Sole Inventor*, 110 MICH. L. REV. 709, 740 (2012); *see also* Michael Mattioli, *Communities of Innovation*, 106 NW. U.L. REV. 103, 113–14 (2012) (discussing AUGUSTIN COURNOT, RESEARCHES INTO THE MATHEMATICAL PRINCIPLES OF THE THEORY OF WEALTH 103–04 (Nathaniel T. Bacon trans., Augustus. M. Kelley ed., 1971) (1838)). These types of complementary technologies are sometimes referred to as Cournot complements. Mattioli, *supra*, at 123.

[103] Dan L. Burk & Mark A. Lemley, *Policy Levers in Patent Law*, 89 VA. L. REV. 1575, 1612–13 (2003); Richard R. Nelson, *The Market Economy, and the Scientific Commons*, 33 RES. POL'Y 455, 464 (2004); Shapiro, *supra* note 72, at 123.

[104] Lemley, *supra* note 3, at 613–14; Reynolds, *supra* note 1, at 86.

[105] Shapiro, *supra* note 72, at 119–20. *But see* Burk & Lemley, *supra* note 103, at 1627 (distinguishing patent thickets as occurring from the need to integrate multiple overlapping intellectual property rights and patent anticommons as occurring from the need to integrate multiple inputs, including intellectual property rights).

[106] D'Silva, *supra* note 12, at 301–02; Lemley, *supra* note 3, at 618.

new patent applications accelerating over time, the risk of underuse and obstruction due to anticommons or other hold ups could just grow worse.

In a Coasean world of zero transaction costs,[107] however, even highly balkanized patent rights could be easily overcome through bargaining and exchange. Where parcelized patent rights are owned by the same entity in a patent portfolio, for example, holdup problems are unlikely to occur. When patent rights are distributed among multiple owners, however, transaction costs become an issue, particularly when conflicting interests, rent-seeking, strategic behavior, and cognitive biases frustrate agreement to use the patents jointly.[108] University ownership of patents as well as the potentially cross-disciplinary relevance of those patents make transaction costs an even greater concern in nanotech.

Again, university TTOs have different interests, expertise levels, and governance structures than do the private industry actors with whom they might negotiate licenses, a factor that can significantly exacerbate transaction costs. Horizontal competitors with similar values and interests will find it easier to come to formal or informal agreements, particularly if repeated over time.[109] Similarly situated private firms with patent portfolios of similar value, for example, may face little difficulty in cross licensing their portfolios. Universities obviously have very different interests and incentives than private industry, however, and agreeing on terms for licensing university patents is often a long and laborious process. These types of conflicts are what this author has previously termed "qualitative," as opposed to a "quantitative" anticommons, in which, regardless of the number of rights holders, the heterogeneity of transacting parties and the divergence of their respective interests and incentives can multiply transaction costs.[110]

Differences of opinion may hinder patent licensing in other ways as well. Rights holders may attempt to hold out for a disproportionate share of any joint rents, for example, knowing that their contribution is essential to the success of the project.[111] Universities in particular tend to overestimate the value of their contributions to downstream development, as the academic mindset typically places greater value on research than on commercialization.[112] Universities frequently demand reach-through

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[107] Reynolds, *supra* note 1, at 84.

[108] Heller & Eisenberg, *supra* note 59, at 698.

[109] *See* Lemley, *supra* note 3, at 622.

[110] Mark D. West & Emily M. Morris, *The Tragedy of the Condominiums: Legal Responses to Collective Action Problems After the Kobe Earthquake*, 51 AM. J. COMP. L. 903, 928 n.69 (2003); *see also* Henry E. Smith, *Intellectual Property as Property: Delineating Entitlements in Information*, 116 YALE L.J. 1742, 1776 (2007) (noting heterogeneity of interests increases transaction costs); Heller & Eisenberg, *supra* note 59, at 698 (same); MILLER ET AL., *supra* note 5, at 76 (same).

[111] Burk & Lemley, *supra* note 103, at 1611–12.

[112] Heller & Eisenberg, *supra* note 59, at 701. Unlike so-called patent trolls, however, universities are unlikely to try to extort rents from unwitting infringers. *See* Mark A. Lemley, *Are Universities Patent*

licenses to downstream products as well, allowing them to extract an even greater share of any returns from commercialization.[113]

The cross-industry applicability of basic nanotech inventions and research also allows universities and other upstream patent holders to exert unusually broad influence over downstream development in a wide number of fields. Universities and even private industry may be able to influence nanotechnology development not only in their own industries but also in other industries as well. The cross-industry applicability of nanotech patents thus raises the risk of both qualitative and quantitative anticommons, as the number of parties needing to license nanotech patents, as well as the number of nanotech patents themselves, increase with the number of industries affected.[114]

Simply having to pay licensing fees or royalties for one or more "upstream" patents reduces incentives to invest in downstream development,[115] and the more patents that must be licensed, the more that royalties must be stacked, and the more that incentives to invest in development are reduced.[116] And where invention costs are low, such as when invention costs are subsidized by the government, patents serve not so much to spur technological development as to deter it.[117] In these circumstances, a fully competitive environment at the margins—i.e., one without patent protections—would better foster downstream development.[118] Releasing government-funded university research into the public domain, for example, would permit interested firms free access to the research to commercialize it.[119] For many technologies competition is more effective than monopoly in spurring development; inventive concepts are nonrivalrous, allowing every interested firm to try their hands at developing downstream applications.[120]

Some of the concerns about nanotech patents have been tempered already, however. For example, some critics suggest tightening the utility and patentable subject matter standards to restrict patenting of upstream research largely in reaction to the flood of biotechnology research patent

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Trolls?, 18 FORDHAM INTELL. PROP. MEDIA & ENT. L.J. 611, 629 (2008).

[113] A PATENT SYSTEM FOR THE 21ST CENTURY 71 (Stephen A. Merrill et al. eds., 2004) [hereinafter A PATENT SYSTEM]; Heller & Eisenberg, *supra* note 59, at 699; Osenga, *supra* note 52, at 427.

[114] *Cf.* Mattioli, *supra* note 102, at 113–14 (discussing Cournot's theory that the more rights that have to be licensed, the greater the cost as compared to rights ownership by single entity).

[115] Michael J. Meurer, *Business Method Patents and Patent Floods*, 8 WASH. U.J.L. & POL'Y 309, 323 (2002).

[116] Mark A. Lemley & Carl Shapiro, *Patent Holdup and Royalty Stacking*, 85 TEX. L. REV. 1991, 2012 (2007); Michael S. Mireles, *An Examination of Patents, Licensing, Research Tools, and the Tragedy of the Anticommons in Biotechnology Innovation*, 38 U. MICH. J.L. REFORM 141, 170 (2004).

[117] Burk & Lemley, *supra* note 103, at 1620–24.

[118] Merges & Nelson, *supra* note 59, at 843–44.

[119] Eisenberg, *supra* note 45, at 1702, 1710–11.

[120] Burk & Lemley, *supra* note 103, at 1604–08 (and sources cited therein); Merges & Nelson, *supra* note 69, at 843–44.

applications.[121] The Supreme Court's recent decisions in *AMP v. Myriad*[122] and *Mayo v. Prometheus*[123] have done exactly that, increasing the likelihood that "discoveries" of naturally occurring materials or principles will be found unpatentable.[124] The courts and the USPTO similarly have tightened the utility requirement to require "specific, substantial, and credible utility" as more than just an object of further research.[125] Moreover, the patent system now also limits patentability by interpreting many patents in new technologies rather narrowly through both the enablement requirement and the written description requirement, the latter of which also is most often applied to narrow university-held biotechnology patents.[126] And regardless, those who advocate for tightening patentability standards acknowledge that more stringent requirements will not completely solve any anticommons problem in nanotechnology, nor will it eliminate upstream research patenting.[127]

Moreover, tightening patentability standards does little to address the other issues that may predispose nanotechnology and other fields to holdup problems with the increase in university patenting under Bayh-Dole. Commentators have therefore proposed various mechanisms to diminish the risk of anticommons and other obstacles. Some of these proposals, such as resurrecting an experimental-use exception in patent law[128] and resurrecting

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[121] *E.g.*, Reynolds, *supra* note 1, at 101–12 (arguing for adoption of a stricter utility requirement).

[122] Ass'n Molecular Pathology v. Myriad Genetics, Inc., 133 S. Ct. 2107 (2013).

[123] Mayo Collaborative Servs. v. Prometheus Labs., 132 S. Ct. 1289 (2012).

[124] *See Ass'n Molecular Pathology*, 133 S. Ct. at 2109–11 (holding isolated DNA sequences to be unpatentable products of nature); *Mayo Collaborative Servs.*, 132 S. Ct. at 1290–91 (holding dosing method based on blood metabolite levels to be an unpatentable law of nature).

[125] Heightened utility standards were first promulgated in an interim form in 1999 and later finalized in 2001. Utility Examination Guidelines, 66 Fed. Reg. 1,092 (Jan. 5, 2001); Revised Utility Examination Guidelines, Request for Comments, 64 Fed. Reg. 71,440 (Dec. 21, 1999); *see also In re* Fisher, 421 F.3d 1365 (Fed. Cir. 2005) (adopting the 2001 Utility Examination Guidelines); Adelman & DeAngelis, *supra* note 67, at 1687–90 (noting that the number of biotech applications granted have decreased due to the USPTO's tightened utility requirement in its 1999 Guidelines, among other factors); Rai, *supra* note 69, at 840 (characterizing the new standards as "a more balanced position").

[126] Dan L. Burk & Mark A. Lemley, *Biotechnology's Uncertainty Principle*, 54 CASE W. RES. L. REV. 691, 695–700 (2004); Burk & Lemley, *supra* note 103, at 1653–54; Rai, *supra* note 69, at 840–41.

[127] *See, e.g.*, Reynolds, *supra* note 1, at 84. For more detailed discussion of patentability requirements and upstream university patenting under the Bayh-Dole Act, see Emily M. Morris, *The Many Faces of Bayh-Dole*, 54 DUQ. L. REV. 81, 117–18 (2016).

[128] *E.g.*, Rochelle Dreyfuss, *Protecting the Public Domain of Science: Has the Time for an Experimental Use Defense Arrived?*, 46 ARIZ. L. REV. 457, 470 (2004); Janice M. Mueller, *No "Dilettante Affair": Rethinking the Experimental Use Exception to Patent Infringement for Biomedical Research Tools*, 76 WASH. L. REV. 1, 5, 9–10, 17 (2001) [hereinafter Mueller, *Dilettante*]; Mireles, *supra* note 47, at 276–77; *see also* Maureen A. O'Rourke, *Toward a Doctrine of Fair Use in Patent Law*, 100 COLUM. L. REV. 1177, 1180–81, 1191, 1198, 1205 n.118 (2000) (proposing import into patent law of fair-use type of exemption similar to that in copyright law under 17 U.S.C. § 107 (2000)). Patent law in the U.S. has, in modern times, reduced its experimental-use exception into near nonexistence. *See* Madey v. Duke Univ., 307 F.3d 1351, 1362 (Fed. Cir. 2002) (concluding that no experimental-use exemption applies where research is the "legitimate business" of the alleged infringer); Janice M. Mueller, *The*

the reverse doctrine of equivalents,[129] are designed to reduce transaction costs by removing the need to license upstream patents. Other proposals, such as less frequent injunctive relief,[130] more accurate apportionment of damages,[131] and limitations on treble damages for willful infringement,[132] seek to lessen the effect of royalty stacking by limiting infringement remedies. A third proposal, specific to Bayh-Dole, calls for the use of a funding agency's "march-in" rights under the Act to grant, under certain circumstances, what are effectively compulsory licenses that allow third parties greater access to patented technologies.[133] A similar proposal calls for government agencies to invoke their rights under the Act to disallow retention of patent rights by funding recipients in "exceptional circumstances" where it "will better promote the policy and objectives" of Bayh-Dole.[134] Finally, private ordering may also help reduce transaction

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Evanescent Experimental Use Exemption from United States Patent Infringement Liability: Implications for University and Nonprofit Research and Development, 56 BAYLOR L. REV. 917, 918 (2004); Katherine J. Strandburg, *What Does the Public Get? Experimental Use and the Patent Bargain*, 2004 WIS. L. REV. 81, 99 (2004); Peter Lee, Note, *Patents Paradigm Shifts, and Progress in Biomedical Science*, 114 YALE L.J. 659, 683–84 (2004). The only substantial experimental-use exception that currently exists in patent law is the statutory exception limited to uses "reasonably related to the development and submission of information under a Federal law which regulates the manufacture, use, or sale of drugs or veterinary biological products." 35 U.S.C. § 271(e)(1) (2012).

[129] *E.g.*, Burk & Lemley, *supra* note 103, at 1657–58; Dreyfuss, *supra* note 128, at 469. The reverse doctrine of equivalents is an equitable doctrine that states that, even if an accused device falls within the literal meaning of a patent claim, no infringement liability will be found if the accused device "so far changed in principle from a patented article that it performs the same or a similar function in a substantially different way." Scripps Clinic & Research Found. v. Genentech, Inc., 927 F.2d 1565, 1581 (Fed. Cir. 1991) (internal quotation marks omitted) (quoting Graver Tank & Mfg. Co. v. Linde Air Prod. Co., 339 U.S. 605, 607, 608 (1950)).

[130] *E.g.*, Peter Lee, *The Evolution of Intellectual Infrastructure,* 83 WASH. L. REV. 39, 102–20 (2008); Mark A. Lemley, *Ten Things to Do About Patent Holdup of Standards (And One Not To)*, 48 B.C. L. REV. 149, 161, 166–67 (2007); Burk & Lemley, *supra* note 103, at 1665–68. *But see* F. Scott Kieff, *Property Rights and Property Rules for Commercializing Inventions*, 85 MINN. L. REV. 697, 732–36 (2001) (advocating for continued use of injunctive relief).

[131] *E.g.*, Lemley, *supra* note 130, at 165–66.

[132] *See, e.g.*, Katherine J. Strandburg, *Curiosity-Driven Research and University Technology Transfer*, *in* 16 UNIVERSITY ENTREPRENEURSHIP AND TECHNOLOGY TRANSFER: PROCESS, DESIGN, AND INTELLECTUAL PROPERTY 93, 113 (Gary D. Libecap ed., 2005); A PATENT SYSTEM, *supra* note 113, at 108–09; Lemley, *supra* note 130, at 164–65; Lemley, *supra* note 3, at 630; *see also* Mireles, *supra* note 47, at 261 (discussing more robust research exemptions in the EU and Japan).

[133] Specifically, a funding government agency may force a funding recipient to grant nonexclusive or exclusive license to another under four circumstances: where the patentee is not expected to achieve "practical application" of the patented invention within "reasonable time;" where necessary to address health and safety needs; where necessary to meet requirements for public use specified under federal law; or to make sure that any manufacturing is substantially domestic. 35 U.S.C. § 203 (a)(1)–(4) (2012); Peter S. Arno & Michael H. Davis, *Why Don't We Enforce Existing Drug Price Controls? The Unrecognized and Unenforced Reasonable Pricing Requirements Imposed upon Patents Deriving in Whole or in Part from Federally Funded Research*, 75 TUL. L. REV. 631, 647 n.93, 648 (2001); Rai & Eisenberg, *supra* note 45, at 294.

[134] *See e.g.*, Rai & Eisenberg, *supra* note 45, at 293, 303, 310 (discussing 35 U.S.C. § 202 (a)(i)–(ii)); *see also* Tullis, *supra* note 12, at 306 (discussing possibility of compulsory licensing under agencies'

costs. Universities can join with other patent holders to form patent portfolios, patent pools, open-source pools, collective-rights organizations, or research and development consortia, all of which can simplify the process of gaining access to relevant patents.[135]

In the end, however, all of these proposals to fix patent holdup problems in nanotechnology matter little if the seemingly slow development is not due to patenting, as a closer look at the technology strongly suggests. The next Section explores this possibility in more detail.

III. THE STORY OF SCIENCE-BASED TECHNOLOGIES: THE IRRELEVANCE OF PATENTS

Contrary to Professor Lemley's assertion, nanotechnology may not be so different from other technologies that have also been affected by the Bayh-Dole Act. Many of the concerns voiced about nanotechnology patents are the same concerns that have been voiced about patents in other fields of university research. Patent floods, for example, have been seen in other new technologies such as molecular biology, superconductors, and petroleum refining, where scientific breakthroughs suddenly spur a rush of new opportunities.[136] Patent floods, in turn, often breed poor patent quality, as the sheer volume of new patent applications strains the USPTO's resources and low-quality and overlapping patents may lead to patent thickets.[137] Indeed, patent thickets have been cropping up since long before the Bayh-Dole Act and the recent expansion of upstream research patenting by universities; thickets were a well-recognized issue in the sewing machine war of the 1850s and in conflicts over airplane patents in the early 1900s, for example.[138] More recently, biotech has seen similar complaints about overly broad patenting, poor patent quality, unpatentable subject matter, and high

§ 202(c)(4) right to "nonexclusive, nontransferable, irrevocable, paid-up license to practice or have practiced for or on behalf of the United States any subject invention") (citations omitted).

[135] *See* Peter Lee, *Contracting to Preserve Open Science: Consideration-Based Regulation in Patent Law*, 58 EMORY L.J. 889, 915–16 (2009) (giving examples of patent pools and open-source software); Robert P. Merges, *Contracting into Liability Rules: Intellectual Property Rights and Collective Rights Organizations*, 84 CAL. L. REV. 1293, 1298 (1996) (suggesting that the law should allow "private collective rights organizations" to develop); Shapiro, *supra* note 72, at 119 ("Cross licenses and patent pools are two natural and effective methods used by market participants to cut through the patent thicket . . . ."); Lemley, *supra* note 3, at 623–27 (arguing that open licensing may be the solution to patent floods); Rai, *supra* note 69, at 845–46 ("[P]roperly designed cross-licensing and patent pooling arrangements can promote innovation markets.").

[136] Merges & Nelson, *supra* note 69, at 907–08; Meurer, *supra* note 115, at 319, 324–25.

[137] Meurer, *supra* note 115, at 323–24; *see also* Adelman & DeAngelis *supra* note 67, at 1710–11 (noting backlog of patent applications in complex technologies such as biotechnology).

[138] Adam Mossoff, *The Rise and Fall of the First American Patent Thicket: The Sewing Machine War of the 1850s*, 53 Ariz. L. Rev. 165, *passim* (2011).

patent clearance costs.[139]

In these and other ways, nanotech appears to be fairly typical of science-based technologies, as this Section explains.[140] There is therefore good reason to believe that at least some of future downstream nanotech development will follow in the footsteps of biotech development, where upstream patenting has turned out to be largely irrelevant. Rather, there are much more important obstacles than upstream patents to development in science-based fields such as biotechnology and nanotechnology: long development cycles; difficulties in attracting private investment; limited access to materials and equipment; high dependence on tacit knowledge; the low expected commercial values; multidisciplinarity; and likely regulatory hurdles. Science-based fields arise from university research, but even when present, access or lack of access to upstream university research patents often takes a back seat to other more salient characteristics of such technologies.

A. *Anticommons Require More Than Upstream Patenting*

As a first matter, the fact that universities hold such a high number of early-stage nanotechnology research patents is not by itself sufficient to cause either qualitative or quantitative holdup problems. Anticommons require more than just a large volume of patents. Patents vary a great deal in scope and importance,[141] and of the small percentage that have commercial value, few will be important enough to create obstacles. Rather, the effect of a patent depends on a number of variables, and the effect of patenting under the Bayh-Dole Act therefore will vary greatly across and even within technologies and their developmental pathways.[142]

To see this point, we can compare nanotechnology to biotechnology. As in nanotechnology, basic academic research and other government-funded research have played a large role in the development of biotechnology.[143] And like nanotech, biotech experienced a surge in university patenting after Bayh-Dole; universities currently hold about 18% of all patents in genetics

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[139] *See, e.g.*, MICHAEL HELLER, THE GRIDLOCK ECONOMY 65 (2008) (summarizing studies suggesting overabundance and poor quality of biotechnology patents); Gary Pulsinelli, *Share and Share Alike: Increasing Access to Government-Funded Inventions Under the Bayh-Dole Act*, 7 MINN. J.L. SCI. & TECH. 393, 438 n.280 (2006) (noting criticisms of USPTO's evaluation of biotechnology patents).

[140] *See, e.g.*, Ulrich Schmoch & Axel Thielmann, *Cyclical Long-Term Development of Complex Technologies—Premature Expectations in Nanotechnology?*, 21 RES. EVAL. 126, 126 (2012) (characterizing nanotechnology as a "science-based complex technology").

[141] Adelman & DeAngelis, *supra* note 67, at 1682.

[142] Brett M. Frischmann, *Commercializing University Research Systems in Economic Perspectives: A View from the Demand Side*, *in* 16 UNIVERSITY ENTREPRENEURSHIP AND TECHNOLOGY TRANSFER: PROCESS, DESIGN, AND INTELLECTUAL PROPERTY 156–57 (Gary D. Libecap ed., 2005); Burk & Lemley, *supra* note 103, at 1584–87; Merges & Nelson, *supra* note 69, at 843.

[143] Bawa, *supra* note 3, at 722; Tullis, *supra* note 12, at 286–90.

and molecular biology.[144] In fact, some observers suggest that as a science-based field, nanotech now is following the same developmental trajectory that biotech charted about fifteen to twenty years ago.[145] The trends seen in biotech can therefore be informative in studying development trends in nanotech.

The empirical evidence thus far is equivocal at best as to whether the increase in university patenting has in fact either impeded or aided downstream development of university-based research as a whole,[146] largely because of the difficulties of testing such a hypothesis.[147] In biotech, however, the empirical data suggests that while anticommons and other holdup effects have affected specific fields such as genetics,[148] biotech more generally does not suffer from significant holdup problems, whether qualitative or quantitative.[149] Some studies suggest that biotechnological development and commercialization have in fact skyrocketed since the 1980s.[150]

The reasons for this surprising absence of evidence of holdup problems in biotech are manifold.[151] First, researchers, especially those in academia, just ignore patents as a general rule.[152] University researchers do not look at

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[144] Adelman, *supra* note 51, at 997 (although Adelman notes that biotech patenting levels overall may be declining); Lee, *supra* note 135, at 939–40.

[145] Frank T. Rothaermel & Marie Thursby, *The Nanotech Versus the Biotech Revolution: Sources of Productivity in Incumbent Firm Research*, 36 RES. POL'Y 832, 842 (2007); Michael R. Darby & Lynne G. Zucker, *Grilichesian Breakthroughs: Inventions of Methods of Investing and Firm Entry in Nanotechnology* 2 (Nat'l Bureau of Econ. Research, Working Paper No. 9825, 2003), http://www.nber.org/papers/w9825 [https://perma.cc/RP29-2Y59].

[146] Osenga, *supra* note 52, at 410; Wolrad Prinz zu Waldeck und Pyrmont, *Research Tool Patents After* Integra v. Merck*–Have They Reached a Safe Harbor?*, 14 MICH. TELECOMM. & TECH. L. REV. 367, 387–88 (2008); Mireles, *supra* note 47, at 261, 274.

[147] *See* Charles R. McManis & Sucheol Noh, *The Impact of the Bayh-Dole Act on Genetic Research and Development: Evaluating the Arguments and Empirical Evidence to Date*, *in* PERSPECTIVES ON COMMERCIALIZING INNOVATION 435, 440, 475 (F. Scott Kieff & Troy A. Paredes eds., 2012) (giving examples of practical barriers to researching whether university patents inhibit innovation).

[148] *See, e.g.*, Mildred K. Cho et al., *Effects of Patents and Licenses on the Provision of Clinical Genetic Testing Services*, 5 J. MOLECULAR DIAGNOSTICS 3, 8 (2003); Jon F. Merz et al., Letter to the Editor, *Industry Opposes Genomic Legislation*, 20 NATURE BIOTECHNOLOGY 657 (2002). *But see* Andrew W. Torrance, *Open Source Biotechnology: Open Source Human Evolution*, 30 WASH. U.J.L. & POL'Y 93, 123 (2009) (pointing out that empirical evidence of anticommons due to gene patenting is scarce and that some empirical evidence in fact suggests the exact opposite).

[149] *See, e.g.*, John P. Walsh et al., *Effects of Research Tool Patents and Licensing on Biomedical Innovation*, *in* PATENTS IN THE KNOWLEDGE-BASED ECONOMY 289, 331 (Wesley M. Cohen & Stephen A. Merrill eds., 2003); Adelman, *supra* note 51, at 1023, 1028–29.

[150] *See* Kieff, *supra* note 130, at 725–26.

[151] Rebecca S. Eisenberg, *Noncompliance, Nonenforcement, Nonproblem? Rethinking the Anticommons in Biomedical Research*, 45 HOUS. L. REV. 1059, 1063–75 (2008); Rebecca S. Eisenberg, *Proprietary Rights and the Norms of Science in Biotechnology Research*, 97 Yale L.J. 177, 197–205 (1987).

[152] Eisenberg, *supra* note 151, at 1076.

patents in selecting their topics and conducting research,[153] and many report that they regularly use patented technologies in the belief that research is exempted from liability under an experimental-use exception.[154] Although the Federal Circuit has held that no such experimental-use exception applies even to university research,[155] research patent infringement is often too difficult to detect and police,[156] particularly when it involves "problem-specific" rather than foundational research, and in any event it is unlikely to be worth enough in damages to justify filing suit.[157] Not surprisingly, patent holders have been ill disposed toward suing academic infringers,[158] but universities may be reaching a point where they can no longer rely on effective immunity from suit for infringement. Universities have increasingly become the instigators and even targets of patent-enforcement threats,[159] and with the growing view of universities as commercial actors, they have increasingly become the targets of patent enforcement as well.[160]

A second, more specific, and perhaps more important reason why biotech has not experienced many hold ups is that biotech still offers so many research and development prospects that neither those in academia nor in private industry need bump into one another in order to research and develop their own patch of biotech.[161] As Professor David Adelman has argued, the opportunities in biotech still far outnumber current research and development capacity, such that those in the field still have plenty of

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[153] *See, e.g.*, John P. Walsh et al., *View from the Bench: Patents and Material Transfers*, 309 SCI. 2002 (2005) (noting that only 5% of scientists surveyed regularly check for patents when conducting research).

[154] A PATENT SYSTEM, *supra* note 113, at 72; Walsh et al., *supra* note 149, at 331.

[155] Madey v. Duke Univ., 307 F.3d 1351, 1362–63 (Fed. Cir. 2002); *see also* A PATENT SYSTEM, *supra* note 113, at 73, 76–77 (noting the effect of *Madey*).

[156] Lemley, *supra* note 3, at 623; Mireles, *supra* note 47, at 275–76 (and sources cited therein).

[157] Lemley, *supra* note 3, at 623; *see also* Victor H. Polk, Jr. & Roman Fayerberg, *When Patented Technologies Get Put to Experimental Use: Practical Considerations for Nanotech R&D*, 8 NANOTECH. L. & BUS. 152, 153–54 (2011) (noting that damage remedies may be muted, depending on the method of infringement).

[158] Walsh et al., *supra* note 149, at 326–27; Heller & Eisenberg, *supra* note 59, at 700–01.

[159] *See* Christopher Brown, *Ayresian Technology, Schumpeterian Innovation, and the Bayh-Dole Act*, 43 J. ECON. ISSUES 477, 479 (2009) ("[U]niversities are heavily involved in patent litigation."); A PATENT SYSTEM, *supra* note 113, at 73, 76–77; Lemley, *supra* note 3, at 622; *see also* Mueller, *Dilettante*, *supra* note 128, at 3–4 (describing Roche's suit against more than forty U.S. universities and others for alleged infringement of patents on the use of "Taq" and PCR).

[160] *See, e.g.*, Jay P. Kesan, *Transferring Innovation*, 77 FORDHAM L. REV. 2169, 2183 (2009) ("[O]verpatenting by universities could lead to universities being treated more like commercial actors . . . ."); Peter Lee, *Patents and the University*, 63 DUKE L.J. 1, *passim* (2013); Mireles, *supra* note 47, at 275–76; Nelson, *supra* note 103, at 466. If the infringement occurs within public universities and research institutions, however, the Supreme Court's decision in *Florida Prepaid Post-Secondary Ed. Expense Bd. v. Coll. Savings Bank*, 527 U.S. 627 (1999) may provide sovereign immunity from suit. BUREAU OF NATIONAL AFFAIRS, INTELLECTUAL PROPERTY TECHNOLOGY TRANSFER 28, 59–60 (Aline C. Flower ed. 2d ed. 2014) [hereinafter BNA]; A PATENT SYSTEM, *supra* note 113, at 78–79; Eisenberg, *supra* note 151, at 1092.

[161] Adelman, *supra* note 51, at 998–99; Walsh et al., *supra* note 149, at 331–32.

freedom to operate within the biotech field.[162] In those cases where researchers were deterred by the cost of licensing upstream patents, the researchers were easily able to redirect their research efforts to alternative strategies, given that most subject matter offered a range of research approaches.[163] Similarly, patented processes and even research-method patents can often be circumvented if other processes for achieving the same result are available.[164] Studies have shown that biotech firms and other researchers will often invent around patented research or use other research tools if any given project would require too many patent licenses.[165] And although biotech has also seen a surge in overall patenting and in upstream patenting in particular,[166] the concentration of patenting in any one subfield of biotech remains small.[167]

Patent ownership also remains fairly diffuse, with no one entity able to exert much control over the field and few barriers to patenting and entry by newcomers.[168] Diffuse patent ownership can lead to increased transaction costs, but in the case of biotech, the number of patents that have to be evaluated and negotiated for any given biotech project remains manageable and is rarely reported as an obstruction.[169]

Without a similar mapping of nanotech-patenting patterns, it is difficult to tell whether nanotechnology also provides wide range of research avenues, but it seems likely. The youth of the field and its vast number of subfields suggest that nanotech is still wide open for exploration without fear of an anticommons.[170] Again, the likelihood of upstream patenting deterring downstream development is a question of how important those upstream patents are. Much like biotech, nanotech is new enough and complex enough that, even with the high levels of patenting on upstream research that nanotech has already seen, many more research opportunities likely have yet

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[162] *See* Adelman & DeAngelis, *supra* note 67, at 1699.

[163] Walsh et al., *supra* note 149, at 303; *see also* Adelman, *supra* note 51, at 1003–04 (noting that most diseases offer more potential research targets than there are available researchers).

[164] *See* Rebecca S. Eisenberg, *Limiting the Role of Patents in Technology*, 5 J. NIH RES. 20, 22 (1993); *see also* A PATENT SYSTEM, *supra* note 113, at 72 (noting that patents can be circumvented by inventing around them, using substitute research tools, and locating research activity offshore).

[165] Eisenberg, *supra* note 151, at 1064–65.

[166] Adelman & DeAngelis, *supra* note 67, at 1687 (noting a decline in biotech patents issued as utility standards and USPTO resources tightened).

[167] *Id.* at 1701–02 (noting that most subclasses of biotechnology contained fewer than one hundred patents).

[168] *Id.*

[169] *Id.* at 1697 (citing Walsh et al., *supra* note 149, at 299–304); A PATENT SYSTEM, *supra* note 113, at 72.

[170] *Cf.* Adelman & DeAngelis, *supra* note 67, at 1698–1700 (explaining how biotechnology's relative youth continues to allow new avenues for exploration).

to be identified.[171]

Likewise, although many basic nanomaterials such as carbon nanotubes, quantum dots, fullerenes, nanowires, dendrimers, and nanorods have been patented,[172] it seems likely that useful additions and alternatives to these materials can be found in the near future. Organic nanotubes and polymer nanotubes, for example, can serve as alternatives to carbon nanotubes for many applications,[173] and carbon nanotubes can be both synthesized and purified through a wide variety of alternative methods.[174] Nanoscopic dendrimers also come in a huge variety of forms, including graphite-like dendrimers, dendrimers with cross-linked surfaces, hyper-branched dendrimers, and more.[175] Most or all of these alternative nanotubes, dendrimers, and processes have been patented (and therefore could create patent thickets or other holdup issues),[176] but their number and range demonstrate the breadth of the field and suggest that in nanotech, as in biotech, R&D opportunities far exceed capacity and that nanotech is thus also "an effectively unbounded, uncongested common resource."[177]

A few critical patents may be important enough, however, that despite their relatively small number, restricted access to these patents could create bottlenecks.[178] Many technologies rely on a few pivotal research tools to enable further research and development;[179] without these foundational inventions, further progress in their respective fields would be difficult or impossible.[180] Although very few upstream research patents fall within this

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[171] David E. Adelman, *The Irrationality of Speculative Gene Patents*, *in* 16 ADVANCES IN THE STUDY OF ENTREPRENEURSHIP, INNOVATION & ECONOMIC GROWTH: UNIVERSITY ENTREPRENEURSHIP & TECHNOLOGY TRANSFER 125 (Gary D. Libecap ed. 2005).

[172] Lemley, *supra* note 3, at 613–14; Reynolds, *supra* note 1, at 86, 96.

[173] Michael Lounsbury et al., *The Politics of Neglect: Path Selection and Development in Nanotechnology Innovation*, *in* 21 ADVANCES IN THE STUDY OF ENTREPRENEURSHIP, INNOVATION & ECONOMIC GROWTH: UNIVERSITY ENTREPRENEURSHIP AND TECHNOLOGY TRANSFER 51 (Gary D. Libecap ed. 2010). The fact that carbon nanotubes have become the better-known form is more a matter of "technological momentum" than importance to the field. *Id.*

[174] M. Henry Heines, *Carbon Nanotubes: Tracing Growth of a Young Technology Through Patents*, 7 NANOTECHNOLOGY. L. & BUS. 21, 26–30 (2010) ("The impact of these synthesis patents is further lessened by the existence of a variety of [carbon nanotube] synthesis methods, presenting the manufacturer with a host of alternatives for avoiding infringement of a single patent.").

[175] Alexander Lee, *Examining the Viability of Patent Pools for the Growing Nanotechnology Patent Thicket*, 3 NANOTECH. L. & BUS. 317, 321–22 (2006).

[176] *See, e.g.*, *id.* at 323 (describing dendrimers as being subject to patent thickets).

[177] Adelman, *supra* note 51, at 987; *cf. id.* (discussing why biotech has not suffered from anticommons).

[178] Walsh et al., *supra* note 149, at 305–06.

[179] *See, e.g.*, Lee, *supra* note 130, at 86–91.

[180] Brett M. Frischmann, *An Economic Theory of Infrastructure and Commons Management*, 89 MINN. L. REV. 917, 928, 932 (2005); Brett M. Frischmann & Mark A. Lemley, *Spillovers*, 107 COLUM. L. REV. 257, 268–69 (2007); Lee, *supra* note 130, at 89–91. Foundational inventions have also been referred to variously as "common-method research tools," Adelman, *supra* note 171, at 139, "platform technologies," McManis & Noh, *supra* note 147, at 485, or even "Grilichesian breakthroughs," Darby & Zucker, *supra* note 145, at 1–2 (citing Zvi Griliches, *Hybrid Corn: An Exploration in the Economics of*

category,[181] exclusive rights over foundational tools obviously can stifle development and competition within a field.[182] Evidence suggests that foundational research tools are frequently dedicated to the public domain, however.[183]

Although nanotubes and other nanomaterials have been referred to as the "basic building blocks,"[184] nanotechnology's true foundational tool is probe microscopy; without probe microscopy, nanotechnology could not have become anything more than an interesting theory.[185] Nobel Prize-winning physicist Richard Feynman first suggested the idea of manipulating individual atoms in 1959, but it was not until the invention of the scanning tunneling microscope in 1981 that scientists could actually visualize matter at a high enough magnitude to begin to construct materials atom by atom.[186] The scanning tunneling microscope was followed by the invention of the atomic force microscope in 1989, which became commercially available shortly thereafter and proved to be superior to the scanning tunneling version.[187] Subsequent iterations on probe microscopy have also yielded the magnetic force microscope and the near-field scanning optical microscope.[188] Because nanotechnology could not exist without probe microscopy, patent rights on these foundational research tools could pose a risk to nanotech development.

According to Professor Lemley, nanotech is nevertheless different from other pioneering technologies like computers, biotech, integrated circuits, and lasers; although these fields experienced patent floods after Bayh-Dole, Lemley claims that those patents covered mainly downstream applications or improvements, not foundational technologies.[189] Instead, according to Lemley, the foundational tools in this latter group of technologies were

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Technological Change, 25 ECONOMETRICA 501, 501 (1957)).

[181] Adelman, *supra* note 51, at 1020; Adelman, *supra* note 171, at 139; McManis & Noh, *supra* note 147, at 486.

[182] Nelson, *supra* note 103, at 464.

[183] Adelman, *supra* note 51, at 997–1001; Adelman, *supra* note 171, at 140; Walsh et al., *supra* note 149, at 324–29.

[184] Lemley, *supra* note 3, at 613–14; Reynolds, *supra* note 1, at 86.

[185] *See* MONICA, *supra* note 2, § 1:1 ("Most important to the development of nanotechnology [were] . . . entirely new forms of electron microscopes . . . ."); Zovko, *supra* note 64, at 156 ("[T]echniques such as scanning probe microscopy are essential for manipulating atoms and arranging them in particular molecular configurations . . . . If scanning probe microscopy, carbon nanotubes, or similar fundamental tools are unavailable to research and development entities through purchase or license from patent owners, the scientific progress of nanotechnology will be stifled."); Darby & Zucker, *supra* note 145, at 13–14.

[186] MONICA, *supra* note 2, § 1:1.

[187] Cyrus M. Mody, *Corporations, Universities, and Instrumental Communities: Commercializing Probe Microscopy, 1981-1996*, 47 TECH. & CULTURE 56, 68–69 (2006); Rothaermel & Thursby, *supra* note 145, at 833, 835.

[188] Mody, *supra* note 187, at 56, 57 n.1.

[189] Lemley, *supra* note 3, at 613.

unpatented, freely licensed, or tied up in interference proceedings and litigation for so long that they were effectively unenforceable.[190] In nanotechnology, by contrast, patents cover all but a very few foundational building blocks, making holdup problems much more likely than in previous technologies.[191]

Again, however, whether nanotech is truly different from biotech or other technologies is a matter for debate for a number of reasons. First, many of the basic nanotech building blocks to which Lemley refers are not truly pivotal, even though they may be basic. Again, carbon nanotubes and even quantum dots, fullerenes, nanowires, dendrimers, and nanorods may be basic in the sense that they can be incorporated into a vast variety of downstream applications,[192] but because meaningful substitutes likely can be found, these materials may not pose as great a holdup risk as Lemley suggests.

Second, to the extent that its development has been stifled by patents on foundational research tools like probe microscopy, nanotech is not as unique as Lemley would suggest. Contrary to Lemley's assertion otherwise, some studies suggest that biotech research has in fact experienced holdup effects.[193] Although Cohen and Boyer liberally granted inexpensive, nonexclusive licenses to their patented recombinant DNA technology,[194] foundational research tools such as Cetus Corporation's polymerase chain-reaction technology, Harvard's OncoMouse, and the University of Wisconsin's human embryonic stem cell technology are thought to have hampered progress in biotechnology because of the patent holders' restrictive licensing practices.[195] Thus, although foundational nanotechnology research tools have been patented, it is likely that development in this field is not significantly different from the other science-based technologies that have preceded it.

Third, even foundational technologies become less foundational as

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[190] *Id.* at 610–14.

[191] *Id.* at 613–14.

[192] *Id.*; *see also* Reynolds, *supra* note 1, at 86, 97 ("[N]anotechnology anticommons occurs at the building block level . . . [where] patent holders will likely attempt to stack licenses on future downstream discoveries.").

[193] Nelson, *supra* note 103, at 464.

[194] MARYANN P. FELDMAN, ALESSANDRA COLAIANNI & CONNIE K. LIU, LESSONS FROM THE COMMERCIALIZATION OF THE COHEN-BOYER PATENTS: THE STANFORD UNIVERSITY LICENSING PROGRAM, *in* INTELLECTUAL PROPERTY MANAGEMENT IN HEALTH AND AGRICULTURAL INNOVATION: A HANDBOOK OF BEST PRACTICES 1797, 1797–98 (Anatole Krattiger et al. eds., 2007), http://www.iphandbook.org/handbook/ch17/p22/ [https://perma.cc/M5U5-DR8S].

[195] *See* Lee, *supra* note 130, at 93–96 ("Cetus threatened to aggressively enforce its patent against firms engaged in pharmaceutical development, and even threatened suit against noncommercial, academic researchers who shared their PCR-enabled research with industry. While Cetus did not follow through with its threats, this example demonstrates the risks of strong exclusive rights on an infrastructural resource subject to rapid and widespread adoption."); Mowery, *supra* note 90, at 56; Walsh et al., *supra* note 149, at 296–309.

newly invented alternatives supplement or replace earlier technologies,[196] as illustrated by the multiple forms of probe microscopy that have become available in nanotechnology.[197] Although probe microscopes are not perfectly interchangeable substitutes for one another, the progression from scanning tunneling microscope to atomic force microscope and beyond does at least illustrate the shift in technological bottlenecks over time.[198]

B. *Obstacles to Development in Science-Based Technologies*

Besides patents, nanotechnology faces a number of other, more significant hurdles common in science-based technologies. "Science-based" technologies such as biotechnology and nanotechnology, also known as "research-based" technologies, derive not from practical experience in industrial design and production but instead from the academic pursuit of knowledge for the sake of knowledge, which may then only later have practical application.[199] As Professor Liza Vertinsky has explained, science-based technologies are "knowledge-intensive"[200] and driven primarily by basic research and scientific breakthroughs outside the norm of private industry.[201] And because inventions in science-based fields such as nanotechnology are typically in no more than proof-of-concept form, they are high in development costs and investment risk but low in expected market value.[202] Commercializing technologies still in such early and risky stages of development is well beyond the comfort zone of most private investors.[203] The difficulties inherent to science-based technology

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[196] Kieff, *supra* note 130, at 730–31; *cf.* Mossoff, *supra* note 138, at 204 (noting that patent thickets are contextual "depending on such things as time, available technology, and even commercial or legal norms").

[197] *See* Mody, *supra* note 187, at 56, 57 n.1.

[198] *See* Lee, *supra* note 130, at 74, 86–91 (discussing the "basic suite of infrastructural assets necessary to invent in a given field shift[ing] as technology progresses").

[199] Nelson, *supra* note 103, at 457–59.

[200] Liza Vertinsky, *Universities as Guardians of Their Inventions*, 4 UTAH L. REV. 1949, 1980 (2012).

[201] Bawa, *supra* note 3, at 722; Merges & Nelson, *supra* note 69, at 880, 907–08 (explaining how further innovation can become more "cumulative than science-based"); Mowery, *supra* note 90, at 42–43 (and sources cited therein); *see* Heather Hamme Ramirez, Comment, *Defending the Privatization of Research Tools: An Examination of the "Tragedy of the Anticommons" in Biotechnology Research and Development*, 53 EMORY L.J. 359, 378 (2004) ("Compared to other industries, the biotechnology sector is highly dependent on academic research . . . . [T]he private sector depends on universities for expanding their research capabilities and expertise and for staying informed about important advances in science."). Nanotechnology pioneer K. Eric Drexler describes science-based technologies by distinguishing them from engineering as curiosity-driven rather than results-driven. K. ERIC DREXLER, RADICAL ABUNDANCE: HOW A REVOLUTION IN NANOTECHNOLOGY WILL CHANGE CIVILIZATION 105–10 (2013).

[202] Mowery, *supra* note 90, at 42–43 (and sources cited therein); Chun Hsien Wang et al., *A Study of Nanotechnology R&D Alliance Networking*, 2012 PROC. PICMET '12: TECH. MGMT. EMERGING TECHS. 3497, *passim* (2012); Ramirez, *supra* note 201, at 378.

[203] *See* Bawa, *supra* note 3, at 722.

development are thus much more likely than patents to slow development in these embryonic fields, which are especially prone to suffer from underdevelopment.[204]

Much of the early optimism about pioneering new technologies such as biotech and nanotech and discussion about the effect of patenting in these fields overlook the significant nonpatent obstacles, however, which can often prove to be insurmountable.[205] Very little of the research in these fields and other government-funded research areas is even worth patenting, presumably because of the same lack of commercial value that made it dependent on government funding.[206] Universities must be highly selective in using their limited resources to patent faculty research, and university TTOs usually will avoid the high costs of obtaining patent protection unless industry expresses an interest in a particular technology.[207] Even when universities do decide to assume the cost of obtaining a patent, very few of those patents earn any profit.[208]

Thus, although development of some of the more straightforward nanotechnology applications may be less difficult, much if not most of the field seems to be as yet in a more inchoate state, requiring many additional developmental stages before commercialization can be achieved. Delays or even failure can occur at any one of these stages for any number of reasons. The following are some of the main reasons why much of nanotechnology as science-based technology is so challenging to commercialize.

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[204] Michael Abramowicz, *The Danger of Underdeveloped Patent Prospects*, 92 CORNELL L. REV. 1065, 1070–71 (2007).

[205] Adelman, *supra* note 171, at 125.

[206] Frischmann, *supra* note 142, at 155, 175; Walsh et al., *supra* note 149, at 309 (reporting that only a minority of university-based inventions are patented, even in genetics).

[207] *See* David S. Siegel & Phillip H. Phan, *Analyzing the Effectiveness of University Technology Transfer: Implications for Entrepreneurship Education* 7 (Rensselaer Working Papers in Economics, Number 0426, 2004), www.economics.rpi.edu/workingpapers/rpi0426.pdf [https://perma.cc/M5ZD-R2RL] (noting that TTO and other research administrators "protect[] the university's intellectual property portfolio [and] . . . actively seek to market university-based technologies to companies and entrepreneurs"); BNA, *supra* note 160, at 225, 227–32; McManis & Noh, *supra* note 147, at 454; Interview with Kerbeshian, *supra* note 96. University TTOs often opt to file much less expensive provisional patent applications, but these expire after twelve months unless a fuller and more expensive nonprovisional application is filled. Margo A. Bagley, *Academic Discourse and Proprietary Rights: Putting Patents in Their Proper Place*, 47 B.C. L. REV. 217, 247 (2006).

[208] Brian J. Love, *Do University Patents Pay Off? Evidence from a Survey of University Inventors in Computer Science and Electrical Engineering*, 16 YALE J.L. & TECH. 285, 308–12 (2014) (finding that life science patents are at least more likely to be profitable than other high tech patents); Scotchmer & Maurer, *supra* note 48, at 235; Bagley, *supra* note 207, at 259; *see also* Greenbaum, *supra* note 68, at 359–60 ("[W]hile some licenses may be a boon for universities and some academic inventors, the majority of income derived from licensing of academic innovation nationwide comes out of a handful of licensing offices, most of which predated Bayh-Dole, and even those take relatively little revenue home relative to the costs necessary to generate those innovations.").

1. *Long Development Cycles*

First and most significant is the fact that commercializing science-based technologies requires a good deal of further experimentation and work; regardless of patent burdens, it is simply a laborious and slow process to develop basic research and "bridge the gap from the laboratory to the marketplace."[209] Science-based technologies often explore pioneering new areas well outside existing art but consequently require far more downstream development than other technologies.[210] Having been invented by scientists rather than business people, emerging technologies do not come out of the laboratory in ready-to-market form,[211] and even patentable inventions in these fields typically require several additional stages of development.[212] Taking research-intensive technologies from laboratory proofs of concept to industrial practice necessitates perfecting the invention so that it will perform reliably and can be reproduced in a cost-efficient manner.[213] For example, producing even basic nanotechnology building blocks such as nanotubes, metal oxide nanoparticles, and fullerenes in consistently high-quality form, took quite some time.[214] Each of these additional steps may also be complex and time-consuming, making overall commercialization quite lengthy. Long development cycles and time lags are therefore common in research-intensive fields such as physics, mathematics, and the physical sciences,[215] and nanotechnology has proven to be no exception, with long

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[209] Thomas A. Kalil, *Nanotechnology and the "Valley of Death,"* 2 NANOTECH. L. & BUS. 265, 265–66 (2005) (quoting *Nanotechnology Research and Development Act of 2003: Hearing on H.R. 766 Before the H. Comm. on Sci.*, 108th Cong. 57–58 (2003) (Statement of Alan Marty, Executive-in-Residence of JP Morgan Partners and Advisory Board Member of Nanobusiness Alliance); *accord* Roberto Mazzoleni & Richard R. Nelson, *Economic Theories About the Benefits and Costs of Patents*, 32 J. ECON. ISSUES 1031, 1048 (1998); Mowery, *supra* note 90, at 43; Schmoch & Thielmann, *supra* note 140, at 126.

[210] Bawa, *supra* note 3, at 719; Mowery, *supra* note 90, at 42–43; Wang et al., *supra* note 202, *passim*.

[211] Stuart J.H. Graham & Maurizio Iacopetta, *Nanotechnology and the Emergence of a General Purpose Technology*, 115/116 ANNALS ECON. & STAT. 5, 8 (2014).

[212] Mowery, *supra* note 90, at 44–45 (and sources cited therein); Merges & Nelson, *supra* note 69, at 880, 907–08; Nelson, *supra* note 103, at 457–59; *see also* Jerry G. Thursby & Marie C. Thursby, *University Licensing and the Bayh-Dole Act*, 301 SCI. 1052, 1052 (2003) (citing survey evidence that 45% of university inventions are simply "proof[s] of concept").

[213] *See* Philip E. Auerswald & Lewis M. Branscomb, *Valleys of Death and Darwinian Seas: Financing the Invention to Innovation Transition in the United States*, 28 J. TECH. TRANSFER 227, 229, 229 fig.2 (2003) (outlining a sequential model of development and funding); Kalil, *supra* note 209, at 265–66 (discussing the time and investment required to move a product from the "laboratory to the marketplace") (quoting *Nanotechnology Research and Development Act of 2003: Hearing on H.R. 766 Before the H. Comm. On Sci.*, 108th Cong. 57–58 (2003) (statement of Alan Marty, Executive-in-Residence of JP Morgan Partners and Advisory Board Member of Nanobusiness Alliance).

[214] Lane & Kalil, *supra* note 28, at 52.

[215] DAVID C. MOWERY ET AL., IVORY TOWER AND INDUSTRIAL INNOVATION: UNIVERSITY-INDUSTRY TECHNOLOGY TRANSFER BEFORE AND AFTER THE BAYH-DOLE ACT IN THE UNITED STATES 30 (2004); Mowery, *supra* note 90, at 43.

development spans frequently delaying commercialization.[216]

Commercializing research-based technologies often entails development of new equipment and new materials as well. Translating scientific knowledge into industrial application generally involves implementation through one of the applied sciences such as engineering, information technology, or materials science.[217] The more pioneering these technologies are and the more widespread their effects, the more their successful commercialization will depend on separate scientific and technological developments in infrastructure such as machinery and processes, as well as correlative technologies such as supporting software and information technology.[218] In nanotechnology, for example, the need to develop secondary equipment and processes may be particularly acute, given the cross-disciplinary nature of nanotechnology and the need to adapt it to specific sectors.[219]

The technological translation process may also depend on the cost and availability of existing material assets and machinery.[220] Probe microscopy development, for example, has been heavily influenced by what materials were cheaply and easily available at the time.[221] When academic researchers were working on improving the STM for their own uses, they opted for graphite because it happened to be cheaply available as waste material from United Carbide.[222] Similar material availability issues also shaped the divergent development efforts by STM researchers working in different locations.[223] And even now, lack of access to high quality and reliably reproducible and manufacturable nanomaterials continues to be a stumbling

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[216] Bawa, *supra* note 3, at 719; Festel et al., *supra* note 20, at 55; Lane & Kalil, *supra* note 28, at 50, 52; Rasmus Davidsen, *Nanotechnology Startups: Not the Usual Growth Pattern*, DAFTBLOGGER EJOURNAL (June 15, 2013, 6:36 PM), http://www.daftblogger.com/nanotechnology-startups-not-the-usual-growth-pattern/ [https://perma.cc/Z3DX-64YA].

[217] Merges & Nelson, *supra* note 69, at 880; *see also* Mowery, *supra* note 90, at 43.

[218] Abramowicz, *supra* note 204, at 1071; Auerswald & Branscomb, *supra* note 213, at 230; Graham & Iacopetta, *supra* note 211, at 12; Schmoch & Thielmann, *supra* note 140, at 127. Of course, where the development of auxiliary technologies depends on access to the upstream technologies to which they are complementary, hold up due to patents on those upstream technologies can further exacerbate overall developmental delays. *See, e.g.*, Howard F. Chang, *Patent Scope, Antitrust Policy, and Cumulative Innovation*, 26. RAND J. OF ECON. 34, 34 (1995). It is in the patentees' best interests, however, to license their upstream patents liberally where the value of their upstream technologies in turn depends on the development of complementary technologies. *Id* at 52.

[219] *See* Graham & Iacopetta, *supra* note 211, at 8–9 (noting that nanotechnology's success as a "general purpose technology" depends on the development of related technologies).

[220] *See* Lee, *supra* note 175, at 323 (explaining that the number of nanotechnology applications currently considered commercially viable is small because of the cost of producing even small quantities of dendritic molecules).

[221] Mody, *supra* note 187, at 65–66.

[222] *Id*.

[223] *Id*.

block for nanotech development[224] because materials such as carbon nanotubes and dendritic molecules are rate-limitingly expensive and difficult to find in sufficiently high quantities and quality.[225] Access to materials or research materials can be restrictive in other fields as well; for example, in biofuels the production cost of enzymes and ethanologens is a significant barrier to research.[226] Similarly, the fixed capital costs of retooling or buying new machinery can be prohibitively burdensome.[227] Nanotechnology depends on access to probe microscopes, nanofabrication equipment, modeling software, and other essential but often proscriptively costly tools.[228] For example, faster drying, more efficient autobody nanocoatings have been available for some time now, but the cost of retooling has kept the cash-strapped automobile industry from taking advantage of the new technology.[229]

Given the extreme length of development cycles in science-based technologies, then, those engaged in the commercialization process often simply ignore potential clashes with the patent rights of others, and rationally so.[230] Even when they receive cease-and-desist letters threatening legal action for patent infringement, emerging technology developers know that litigation to enforce patent rights is often more costly than it is worth.[231] In addition, patent holders usually will refrain from filing suit until an infringing development project produces something of enough commercial value to warrant the bother, but given the high failure rates in research-intensive technologies, threatening patent holders seldom actually file.[232] Litigation always poses a risk for the patent holders as well, as even the strongest patents may be subject to invalidation in whole or in part.[233] And if the critics are correct, filing infringement suits in science-based technologies may be particularly fraught with danger, as upstream patents

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224 NAT'L RESEARCH COUNCIL, MANAGING UNIVERSITY INTELLECTUAL PROPERTY IN THE PUBLIC INTEREST 7–8, 31, 38–40 (Stephen A. Merrill & Anne-Marie Mazza eds., 2010) [hereinafter NRC]; Lane & Kalil, *supra* note 28.

225 Lee, *supra* note 175, at 323 ("[T]here are only a handful of [nanotechnology] applications and discoveries that are currently considered commercially viable and worth pursuing due to the very high cost of producing even small quantities of dendritic molecules."); MONICA, *supra* note 2, § 1:10.

226 Daniel R. Cahoy & Leland Glenna, *Private Ordering and Public Energy Innovation Policy*, 36 FLA. ST. U.L. REV. 415, 448–49 (2009).

227 Wolfe, *supra* note 37; *see also* Graham & Iacopetta, *supra* note 211, at 8–9 (noting that the "general purpose technologies," potentially including nanotechnology, often experience slow-downs as existing equipment is replaced with relevant new equipment).

228 MILLER ET AL., *supra* note 5, at 189; Graham & Iacopetta, *supra* note 211, at 12.

229 Wolfe, *supra* note 37.

230 Mark A. Lemley, *Ignoring Patents*, 2008 MICH. ST. L. REV. 19, 20–22 (2008); Walsh et al., *supra* note 149, at 327.

231 Lemley, *supra* note 230, at 22; Lemley, *supra* note 3, at 623; Polk & Fayerberg, *supra* note 157, at 153–54; Walsh et al., *supra* note 149, at 327.

232 Lemley, *supra* note 230, at 22.

233 *See id.* at 27 (noting that as many as three-fourths of litigated patents are found invalid or not infringed); Walsh et al., *supra* note 149, at 328.

are particularly vulnerable to invalidation for lack of specific and substantial utility, failure to claim patentable subject matter, and, especially in nanotechnology, inherency or obviousness.[234]

Finally, development cycles may also span so many years that patents on foundational or other potentially blocking upstream research inputs often will expire in the interim.[235] Patents on many of the basic nanotech building blocks, such as those on carbon nanotubes, buckyballs, quantum dots, dendrimers, and nanorods, for example, have already expired or are due to expire in the very near future,[236] and foundational inventions in particular may be used through several development cycles, such that their patents expire long before their utility does.[237] Thus, by the time science-based technologies finally achieve commercialization, many patents will no longer be in effect.[238] As a result, upstream patenting's capacity to exert holdup effects is rather low in these technologies.

2. *The Valley of Death*

The technological difficulties of commercializing science-based technologies bring economic difficulties as well. Again, commercialization of research-intensive technologies is usually an expensive, risky, multistage undertaking. The government will invest in the basic research stages, but private investors prefer to wait and invest only in the very last stages of development; private firms and investors generally favor development projects closer to completion so as to minimize risk and maximize the time-value of their funds.[239] The long, expensive, and uncertain development stages in between the early, basic research stage and the final, marketing stage are consequently left to languish for lack of investment.[240] Indeed, many scholars note that it is government funding of basic research that "causes" the valley of death because the government tends to subsidize exactly the kind of basic research in which private industry is unwilling to

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[234] HELLER, *supra* note 139, at 65; Akhtar, *supra* note 6, at 138; Bawa, *supra* note 3, at 707–10; Pulsinelli, *supra* note 139, at 438 n.280 ; Williamson & Carpenter, *supra* note 61, at 139–40.

[235] Ted Sichelman, *Commercializing Patents*, 62 STAN. L. REV. 341, 366 (2010); Adelman, *supra* note 51, at 1015–16.

[236] Sharrott & Gupta, *supra* note 4, at 159–60.

[237] Adelman, *supra* note 51, at 1015–16; Sichelman, *supra* note 235, at 366.

[238] To see the inverse relationship between development cycle length and the risk of patent-related hold ups, contrast biotech and nanotech with the software industry, where development cycles are so short that new software may run afoul of patents still covering previous generations of software. Burk & Lemley, *supra* note 103, at 1622–23.

[239] Allen, *supra* note 2; Frischmann, *supra* note 142, at 172; FORD ET AL., *supra* note 49, at 4.

[240] Auerswald & Branscomb, *supra* note 183, at 232; FORD ET AL., *supra* note 49, at 10; Kalil, *supra* note 209, at 265–66. Private investors' willingness to invest in intermediate-stage commercialization has apparently varied somewhat over the years, however. Auerswald & Branscomb*, supra* note 213, at 231; T. Randolph Beard et al., *A Valley of Death in the Innovation Sequence: An Economic Investigation*, 18 RES. EVALUATION 343, 350–51 (2009).

assume the risk.[241] Development of many otherwise valuable science-based inventions never attain commercialization because of lack of funding for the intermediate stages of development in what has been termed the "Valley of Death."[242]

Private investors are reluctant to fund the intermediate stages of technology development for a variety of reasons, many of which are the same reasons that they do not invest in early-stage, basic research. Other things being equal, the more rapidly an investment yields returns the more likely investors are to invest, but research-intensive technologies do not lead to the kind of rapid innovation that can yield the immediate returns that investors want.[243] Instead, science-based technologies still in the early and even intermediate stages of development take too many years to yield returns, if they in fact yield any returns at all.[244] Much of the current development in nanotechnology, for example, commonly requires twice the time needed for commercialization in other venture-capital supported technologies[245] and is well beyond the accepted investment timetables of private industry.[246] Plus, the longer the development cycle, the more costly it is likely to be, making development even more unattractive as an investment.[247]

And it is not just the length of development cycles but also the uncertainty and risk inherent in science-based technologies that deter investment in the intermediate stages of development. Commercialization of basic research is a painstaking process of trial and error,[248] and university-initiated inventions in particular experience higher failure rates than private firm-initiated inventions, with up to half of university inventions failing during commercialization.[249] In addition to the technological uncertainties

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[241] *See, e.g.*, Beard et al., *supra* note 240, at 344; *see generally* FORD ET AL., *supra* note 49, at 12–14 (providing an explanation and conceptualization of the "valley" in order to find out why it exists in the first place).

[242] The chronic underfunding of intermediate technological development has also been referred to as the "Darwinian seas" or "innovation gap." Auerswald & Branscomb, *supra* note 213, at 231. It has also been called the "funding gap." Beard et al., *supra* note 240, at 343.

[243] Abramowicz, *supra* note 204, at 1097.

[244] Auerswald & Branscomb, *supra* note 213, at 232.

[245] Schmoch & Thielmann, *supra* note 140, at 134; Allen, *supra* note 2; *see also* Wolfe, *supra* note 37 (explaining that development in nanotechnology start-ups average seven years from inception to market). *But see* Rothaermel & Thursby, *supra* note 145, at 846 (surmising, on the other hand, that nanotechnology development cycles are half as long as those typical of biotechnology).

[246] Lane & Kalil, *supra* note 28, at 52; *see also* Beard et al., *supra* note 240, at 345 n.3 (citing a Department of Energy report that venture capitalists, as a rule, expect a ten-time return on investments within five years).

[247] Abramowicz, *supra* note 204, at 1093.

[248] Mazzoleni & Nelson, *supra* note 209, at 1048.

[249] Emmanuel Dechenaux et al., *Appropriability and Commercialization: Evidence from MIT Inventions*, 54 MGMT. SCI. 893, 894 (2008); Frank T. Rothaermel & Marie Thursby, *Incubator Firm Failure or Graduation? The Role of University Linkages*, 34 RES. POL'Y 1076, 1078 (2005); *see also*

already mentioned, commercializing science-based inventions also involves the business uncertainties of defining markets and market demand.[250] Technological difficulties account for only about half of the failure rate among university inventions, with the remainder failing due to the business difficulties of identifying market opportunities for university inventions whose ultimate applications so frequently differ from what was expected during the early stages of commercialization.[251] Nanotechnology again has proven to be no exception, with both technological and marketing difficulties leading to high failure rates during commercialization efforts.[252]

Considering the time and expense involved and their minimal capacity even to assess risk, investors are understandably risk averse. The information gaps between inventing research scientists and investors are significant,[253] and few private investors can afford the fixed capital costs of acquiring the expertise necessary to assess the risks.[254] The intermediate stages of development are thus in many ways the most critical because they are the stages that resolve much of the technological and business uncertainty of commercialization.[255] Only once intermediate-stage development is complete, these uncertainties resolved, and a valid commercial plan proven are private investors willing to become involved.[256]

In this way the valley of death and the information gap between private interests and university researchers can create greater obstacles to downstream development than patents do. The difficulties of attracting investment in technologies with long and uncertain development cycles are often a more intractable problem than is the need to license upstream or complementary patents. As a matter of fact, identifying downstream firms to develop university research is one of the most difficult obstacles for technology transfer offices to overcome.[257]

Some private investors such as angel and seed investors specialize in early- and intermediate-stage development, however.[258] Indeed, a few angel

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Thursby & Thursby, *supra* note 212, at 1052 (additional citations omitted) (citing evidence that university inventions have 72% failure rate for proof-of-concept inventions).

[250] Auerswald & Branscomb, *supra* note 213, at 229; Dechenaux et al., *supra* note 249, at 894; Kalil, *supra* note 209, at 265–66.

[251] Dechenaux et al., *supra* note 249, at 894.

[252] Allen, *supra* note 2; Wang et al., *supra* note 202, at 3498.

[253] Auerswald & Branscomb, *supra* note 213, at 230; Graham & Iacopetta, *supra* note 211, at 8–9; Atul Nerkar & Scott Shane, *Determinants of Invention Commercialization: An Empirical Examination of Academically Sourced Inventions*, 28 STRATEGIC MGMT. J. 1155 (2007); Scott Shane, *Selling University Technology: Patterns from MIT*, 48 MGMT. SCI. 122, 123 (2002); Charles W. Wessner, *Driving Innovations Across the Valley of Death*, 48 RES. TECH. MGMT. 9, 9 (2005).

[254] FORD ET AL., *supra* note 49, at 33–34.

[255] Auerswald & Branscomb, *supra* note 213, at 229–30; FORD ET AL., *supra* note 49, at 10; Kalil, *supra* note 209, at 265–66.

[256] Abramowicz, *supra* note 204, at 1071; Auerswald & Branscomb, *supra* note 213, at 229.

[257] Osenga, *supra* note 52, at 421.

[258] Auerswald & Branscomb, *supra* note 213, at 230.

investment companies, such as the Nano Business Angels network and the Central Coast Angel Network, have come to specialize in nanotech specifically.[259] Over time other venture capitalists and other potential investors will become less reluctant to invest in new technologies such as nanotechnology as investors develop expertise in and a level of comfort with the technologies and the technologies themselves mature, such that the perceived risk of investment attenuates.[260] Venture capital's interests in nanotechnology, for example, have waxed and waned over the years,[261] and venture capitalists have constituted only a small minority of overall funding of nanotechnology research for the past couple of decades.[262] Only once revenue streams from nanotechnology-based products finally began to grow in recent years did private industry funding for nanotechnology R&D finally begin to overtake government funding.[263]

Because of private capital's wariness of emerging technologies, development projects that are too uncertain and risky to attract private funding can obtain government funding from several federal agencies.[264] The Small Business Innovation Research (SBIR) program enacted in 1982, for example, allows federal agencies to grant funds to small businesses for the commercialization of government-sponsored R&D.[265] A number of agencies that fund nanotechnology basic research also issue SBIR grants, and the National Institutes of Health have even implemented a Bioengineering Nanotechnology Initiative to grant SBIR funds for biomedical nanotech projects.[266] The Small Business Technology Transfer (STTR) subpart of SBIR also funds collaborations between private industry and nonprofit educational and research facilities.[267] In the late 1980s, Congress also created the Advanced Technology Program (ATP) to provide matching funds for private investments in early-stage technological developments that face significant risk but are likely to yield significant and wide-ranging benefits.[268] Overall, government funding steps in to provide

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259 MILLER ET AL., *supra* note 5, at 190.

260 Auerswald & Branscomb, *supra* note 213, at 232–34.

261 Allen, *supra* note 2; Mark Boslet, *Nanotech Falls Out of Favor (Again) with VCs*, PE HUB (Nov. 11, 2010), http://www.pehub.com/2010/11/nanotech-falls-out-of-favor-again-with-vcs/ [https://perma.cc/J6NU-R3GX]; Tan, *supra* note 96; Wolfe, *supra* note 37.

262 Bawa, *supra* note 3, at 702 n.6.

263 NANOTECHNOLOGY UPDATE: CORPORATIONS UP THEIR SPENDING AS REVENUES FOR NANO-ENABLED PRODUCTS INCREASE, LUX RESEARCH INC. 1–2 (Dec. 2013), https://www.nsf.gov/crssprgm/nano/reports/LUX14-0214_Nanotechnology%20StudyMarketResearch%20Final%2017p.pdf [https://perma.cc/XC8A-QPBJ].

264 BNA, *supra* note 160, at 285–86.

265 Kalil, *supra* note 209, at 266–67.

266 *Id.* at 266–68 (describing inter alia the National Institutes of Health "Bioengineering Nanotechnology Initiative"); MONICA, *supra* note 2 (listing federal agencies funding basic nanotech research).

267 BNA, *supra* note 160, at 285; Vertinsky, *supra* note 200, at 1959 n.30, 2007, 2010.

268 Kalil, *supra* note 209, at 266; Wessner, *supra* note 253, at 9–10.

about 20% to 25% of all funds for early-stage technology development,[269] with state governments also increasingly providing public funds for the same purposes, such as funding university start-ups.[270] Nanotechnology companies can also apply for Defense Advanced Research Projects Agency grants for high-risk projects that offer advances in military preparedness.[271]

3. *Limitations on Equipment and Materials*

Furthermore, constraints on access to the necessary tools and materials as well as skills raise imitation costs in a way that makes patent protections largely inconsequential and even unnecessary in science-based technologies.[272] Private control over relevant research facilities and materials, for example, create nonpatent exclusivities affecting downstream development. Not just industry but also universities are often perceived as being quite proprietary over their materials and instruments, particularly biotech materials, and frequently do not allow the public free access to their research materials and tools.[273] In point of fact, a survey of biotech researchers documents that the need to negotiate access to necessary materials such as cell lines was a more limiting factor than upstream patents.[274] And even when they do agree to share materials and equipment, universities often employ materials-transfer agreements that include reach-through royalty provisions or other restrictive conditions such as limits patenting to downstream products.[275]

Of course, proprietary university policies on sharing research materials may be a part of an overall shift toward less liberal sharing caused by Bayh-Dole's emphasis on university ownership of their research. Universities may feel that they need to be more protective of their research materials and tools as a way of simultaneously protecting their research patents,[276] for instance, or universities may be forced to be more possessive of their materials because of the restrictions imposed under industry-sponsored research

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[269] Auerswald & Branscomb, *supra* note 213, at 232.

[270] *See* Michael MacRae, *Commercializing University Research*, ASME (Mar. 2011), https://www.asme.org/engineering-topics/articles/high-tech-startups/commercializing-university-research [https://perma.cc/RYQ2-QWCZ] (reporting on the state of Oregon's program to help its public university-based start-ups).

[271] MILLER ET AL., *supra* note 5, at 193. Government funding programs for intermediate stage development also may help by signaling to the market which technologies are worth investing in. Wessner, *supra* note 253, at 9–10.

[272] Adelman, *supra* note 51, at 986–87.

[273] BNA, *supra* note 160, at 215–16.

[274] Eisenberg, *supra* note 151, at 1066.

[275] Greenbaum, *supra* note 68, at 362–64; Mowery & Ziedonis, *supra* note 53, at 159.

[276] BNA, *supra* note 160, at 429; Rebecca S. Eisenberg, *Bargaining Over the Transfer of Proprietary Research Tools: Is This Market Failing or Emerging?*, *in* EXPANDING THE BOUNDARIES OF INTELLECTUAL PROPERTY: INNOVATION POLICY FOR THE KNOWLEDGE SOCIETY 223–28 (Rochelle C. Dreyfuss et al. eds., 2001); Mowery & Ziedonis, *supra* note 53, at 159.

agreements relying on the expectation of university patent ownership under Bayh-Dole.[277] On the other hand, universities may be protective simply because producing research materials and tools requires effort and investment and because those materials and tools help universities establish a competitive edge as leading research institutions.[278] Regardless of the motivation, however, the fact stands that exclusive access to research materials and tools is a more significant problem in technology commercialization efforts than patents are.[279]

One method that has been used to address the holdup problems created by the need for research materials is to standardize materials-transfer agreements, at least as between equally situated research institutions such as universities, as proposed by the NIH and endorsed by the AUTM for use in the transfer of biotechnology research materials.[280] This effort fell somewhat flat, however, as universities often may continue to place their economic self-interest over Mertonian norms and social welfare.[281]

Universities have, however, begun to set up technology incubators and research and science parks to house both university- and industry-based start-ups; to facilitate closer relationships between universities and private industry for joint projects, consultation, and other endeavors; and to provide access to research materials and tools.[282] Industry- and university-based "precompetitive" research and development consortia have also recently evolved to share research and development resources, such as research tools,

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[277] BNA, *supra* note 160, at 241; James Flanigan, *Collaborating for Profits in Nanotechnology*, N.Y. TIMES, July 15, 2009, at B6; Arti K. Rai, *Proprietary Rights and Collective Action: The Case of Biotechnology Research with Low Commercial Value* 4 (Duke L. Sch. Legal Stud., Research Paper No. 59, 2004), http://ssrn.com/abstract=568521 [https://perma.cc/UT6Y-YX9P] (noting also a significant increase in proprietary rights over upstream materials in biotechnology research over the past two decades).

[278] Walsh et al., *supra* note 149, at 320 (noting that universities themselves rank commercial concerns at the bottom of the list of reasons for their proprietary attitudes toward research materials and tools).

[279] Eisenberg, *supra* note 151, at 1062; *cf.* Greenbaum, *supra* note 68, at 363 (noting that materials transfer agreements are not subject to the same exceptions that patent and copyright rights are). *But see* Mowery & Ziedonis, *supra* note 53, at 157 (finding evidence that materials transfer agreements do not hinder commercialization of university research).

[280] Uniform Biological Material Transfer Agreement: Discussion of Public Comments Received; Publication of the Final Format of the Agreement, 60 Fed. Reg. 12,771 (Mar. 8, 1995); Arti K. Rai, *Regulating Scientific Research: Intellectual Property Rights and the Norms of Science*, 94 NW. U.L. REV. 77, 113 nn.201–04 (1999); Lee, *supra* note 135, at 925.

[281] Rai, *supra* note 277, at 13; Rai & Eisenberg, *supra* note 45, at 289, 305–06.

[282] Matthew M. Mars & Sherry Hoskinson, *The Organizational Workshop: A Conceptual Exploration of the Boundary Spanning Role of University Entrepreneurship and Innovation Centers*, *in* ADVANCES IN THE STUDY OF ENTREPRENEURSHIP, INNOVATION AND ECONOMIC GROWTH: SPANNING BOUNDARIES AND DISCIPLINES: UNIVERSITY TECHNOLOGY COMMERCIALIZATION IN THE IDEA AGE, *supra* note 95, at 120; BNA, *supra* note 160, at 266–67; Rothaermel & Thursby, *supra* note 249, at 1076–77; Siegel & Phan, *supra* note 207.

materials, and even data.[283] These precompetitive consortia are probably the most effective means of providing public access to otherwise proprietary materials, as the consortia allow multiple downstream developers to share foundational resources. Such precompetitive consortia are difficult to organize, however, and face steep transaction costs that may require governmental intervention, or changes in relevant law, to overcome.[284]

4. *Tacit Knowledge*

Moreover, limited access to research materials and tools is not the only type of nonpatent exclusivity that can obstruct downstream development. Another form of effective exclusivity is tacit knowledge, a phenomenon common in fields such as biotechnology and nanotechnology, where university research can lead to such major advances over the prior art that learning curves become too steep for others in the field to be able to acquire the necessary expertise.[285] As a result, the knowledge and skills necessary for downstream development in the field remain concentrated in the hands of just a few researchers and impose an unavoidable limit on downstream development that often eclipses other types of exclusivity, including both patent protection and first-mover advantages.[286]

First, commercialization of most university research, whether or not patented, requires the participation of the inventing researcher. Estimates indicate that somewhere between 40% and 71% of licensed university research requires faculty involvement to be successfully commercialized.[287] Even genetics remained dependent on tacit knowledge for decades after Cohen & Boyer's seminal invention of recombinant DNA technology.[288] Nanotechnology also remains highly knowledge-intensive, such that success in the field is limited to firms with access to researchers with the requisite specialized skills in the area.[289]

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[283] Liza Vertinsky, *Making Knowledge and Making Drugs? Experimenting with University Innovation Capacity*, 62 EMORY L.J. 741, 763–64 (2013) [hereinafter Vertinsky, *Making Knowledge*]; BNA, *supra* note 160, at 299; *see also* Liza S. Vertinsky, *Patents, Partnerships, and the Pre-Competitive Collaboration Myth in Pharmaceutical Innovation*, 48 U.C. DAVIS L. REV. 1509, 1530–37 (2015) [hereinafter Vertinsky, *The Pre-Competitive Collaboration Myth*]; Matthew Herder, *Patents & the Progress of Personalized Medicine: Biomarkers Research as Lens*, 18 ANNALS HEALTH L. 187, 220 (2009).

[284] Vertinsky, *Making Knowledge*, *supra* note 283, at 808–20; Vertinsky, *The Pre-Competitive Collaboration Myth*, *supra* note 283, at 1517.

[285] Darby & Zucker, *supra* note 145, at 1; Rothaermel & Thursby, *supra* note 145, at 833.

[286] Rothaermel & Thursby, *supra* note 145, at 833; *see generally* Darby & Zucker, *supra* note 145.

[287] Jerry G. Thursby & Marie C. Thursby, *Pros and Cons of Faculty Participation in Licensing*, *in* 16 ADVANCES IN THE STUDY OF ENTREPRENEURSHIP, INNOVATION AND ECONOMIC GROWTH: UNIVERSITY ENTREPRENEURSHIP AND TECHNOLOGY TRANSFER, *supra* note 95, at 192; Darby & Zucker, *supra* note 145, at 4; Rothaermel & Thursby, *supra* note 249, at 1078–79.

[288] *See* Darby & Zucker, *supra* note 145, at 9–10 (suggesting dependence on tacit knowledge in genetics lasted at least as long as the early 2000s after Cohen and Boyer's invention in the early 1970s).

[289] MILLER ET AL., *supra* note 5, at 189; Wang et al., *supra* note 202, at 3497–99.

For example, tacit knowledge was a significant factor in the development of the scanning tunneling microscope and the atomic force microscope, two of the foundational research tools through which the entire field of nanotechnology even became possible.[290] Invented by IBM employees Heini Rohrer and Gerd Binnig in 1979, the STM was at first a commercially valueless dud in which IBM lost interest.[291] Rohrer and Binnig did not want their brainchild to fall into oblivion, however, so they cultivated a select few academic researchers from a variety of disciplines who were interested in using the STM for basic research.[292] This core group of STM enthusiasts struggled for years to acquire enough of Binnig and Rohrer's expertise to replicate the microscope.[293] Only once a critical mass of enthusiasts finally had the expertise to construct STMs on their own and to spark the interests of their home institutions in the research benefits of these new devices did IBM decide to begin commercial STM production in the late 1980s.[294] Even then, for the first five years or so after they were invented, scanning tunneling and atomic-force microscopes were accessible only to those with the resources and skills necessary to construct the microscopes on their own.[295] Moreover, the facilities that invested in STMs still had to train someone to use the microscopes, given that the simple act of using an STM continued to require some degree of expertise and tacit knowledge for decades.[296]

Second, faculty involvement is often crucial to locating licensees for university research. A researcher's tacit knowledge can be important to bridging the information gaps between investors and researchers that contribute to valley-of-death issues and can help to inspire investor confidence by establishing a researcher's reputation and status.[297] In fact, potential licensees are often identified only through a faculty researcher's contacts with industry players[298] and through personal relationships rather than arm's-length marketing.[299]

Of course, like patent protection, first-mover advantages, and other

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[290] *See* Mody, *supra* note 187, at 56.

[291] *Id*. at 60.

[292] *Id.* at 60–61.

[293] *Id.* at 56–57, 60–61.

[294] *Id.* at 60–61.

[295] Darby & Zucker, *supra* note 145, at 14, 25.

[296] Mody, *supra* note 187, at 68.

[297] BNA, *supra* note 160, at 429; *see also supra* notes 253–57 and accompanying text (discussing information gaps between researchers and investors as exacerbating the valley of death).

[298] Samuel Estreicher & Kristina A. Yost, *University IP: The University as Coordinator of the Team Production Process* 12–13 (N.Y.U. Pub. L. & Legal Theory Working Papers, Working Paper No. 489, 2016), http://lsr.nellco.org/nyu_plltwp/489 [https://perma.cc/27QG-RWE7].

[299] Donald Siegel et al., *Assessing the Impact of Organizational Practices on the Productivity of University Technology Transfer Offices: An Exploratory Study* 29–30 (Nat'l Bureau of Econ. Res., Working Paper No. 7256, 1999), http://www.nber.org/papers/w7256 [https://perma.cc/UL2K-8VVS].

types of exclusivity, tacit knowledge is time-limited; tacit knowledge can remain tacit for only so long. As understanding of an emerging technology matures and spreads, others will gain access to the technology. Exactly how long any such tacit knowledge might provide some sort of exclusivity in nanotech development is an open question and likely depends on the particular development at issue, but that being said, at least one study by economists strongly suggests that the duration of nonpatent exclusivity based on tacit knowledge and access to research tools was twice as long in biotech as in nanotech.[300]

While tacit knowledge and other natural exclusivities over university research continue to be in force, however, it is not surprising that commercialization efforts in science-based technologies tend to concentrate geographically around university faculty with the requisite expertise and materials.[301] Geographic collocation has the advantage of allowing hands-on participation by faculty members or others with pivotal tacit knowledge, access to university technology incubators and research parks, and collaboration or even acquisition of university-initiated start-up companies.

Indeed, in the last three decades or so, universities have begun to license their upstream research patents to start-up companies at increasing rates.[302] University start-ups could help solve some of the nonpatent problems in developing upstream research.[303] For example, start-ups may help both transfer tacit knowledge and provide access to research tools and materials. Faculty researchers and their graduate students commonly are active parts of university-based start-ups and have become increasingly active participants in private industry more generally, as research scientists now commonly move between universities and industry and private firms host postdoctoral fellows.[304] The tacit knowledge these students and faculty researchers possess continues to be exclusive to them,[305] of course, until such time that understanding of the underlying technology matures and spreads and becomes less tacit over time.[306] Nonetheless, faculty involvement in start-ups and other private enterprises does at least provide a conduit by

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[300] Rothaermel & Thursby, *supra* note 145, at 846.

[301] Darby & Zucker, *supra* note 145, at 17; *see also* Giovanni Abramo et al., *The Role of Information Asymmetry in the Market for University-Industry Research Collaboration*, 36 J. TECH. TRANSFER 84, 87 (2011) (and sources cited therein).

[302] BNA, *supra* note 160, at 261; Estreicher & Yost, *supra* note 298, at 11–12. As a practical matter, licensing government-funded university research to start-ups fits neatly within Bayh-Dole's preference for licensing to small-businesses. BNA, *supra* note 160, at 29, 207, 261; Rothaermel & Thursby, *supra* note 145, at 833. University-based start-ups are still a relatively infrequent form of technology transfer, however. Kesan, *supra* note 160, at 2189; Estreicher & Yost, *supra* note 298, at 13.

[303] BNA, *supra* note 160, at 261.

[304] Lee, *supra* note 160, at 47.

[305] For this reason, private acquisition of university-based start-ups can aggravate holdup problems by consolidating ownership of pivotal upstream patents, research tools and materials, and knowledge.

[306] Lee, *supra* note 88, at 1525.

which tacit knowledge can be transferred to the commercial sector. Likewise, to the extent that university-based start-ups make use of university research tools and materials, start-ups can provide the commercial sector with at least some, albeit limited, access to tools and materials over which the university might exert proprietary rights.

To a lesser extent, start-ups may also help bridge the valley of death. Although larger or at least established firms might have more expertise in commercializing and marketing generally,[307] start-ups offer their own advantages.[308] University start-ups generally are more nimble and less risk-averse than not only universities but also larger, more established firms.[309] Unlike their parent universities, moreover, university-based start-ups are designed to be commercial entities that presumably will have the kinds of market orientations that universities lack while also avoiding the bureaucracy of university administrations and constituencies. And to the extent that they are funded through alternatives to private investment, university start-ups represent an intermediate (and separately funded and executed) step between upstream research and marketable downstream applications.[310] Start-ups work on the intermediate development stages, making commercialization less risky and more attractive to private investors. And although only a small percentage of licensed university research is introduced through start-ups rather than through more established firms,[311] university-based start-ups are by far the most common way for new nanotechnology businesses to get their start;[312] most nanotech companies today are university-based start-ups.[313]

5. *Multidisciplinarity and Personnel*

One of the most exciting aspects of nanotechnology is its potential to revolutionize an amazingly wide variety of technological and scientific fields. As noted above, however, this cross-industry potential is also one of nanotechnology development's potential drawbacks, although not for the reasons that Professor Lemley and others have posited. Development in multidisciplinary fields involves not just the need to coordinate patents and other legal rights but also the need to coordinate technological expertise from among the relevant fields.[314] Although mixing disciplines can create

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[307] BNA, *supra* note 160, at 261.
[308] Chukumba & Jensen, *supra* note 96, at 4.
[309] BNA, *supra* note 160, at 261; Rothaermel & Thursby, *supra* note 145, at 833.
[310] *See* Heller & Eisenberg, *supra* note 59, at 698.
[311] Mowery, *supra* note 90, at 53.
[312] MILLER ET AL., *supra* note 5, at 140.
[313] *Id.* at 136.
[314] Laura G. Pedraza-Fariña, *Patent Law and the Sociology of Innovation*, 2013 WIS. L. REV. 813, 838–40 (2013); Sharon Tsai-hsuan Ku, *Forming Interdisciplinary Expertise: One Organization's*

new paradigms that spur innovation, such "intellectual migration" is not without its own transaction costs and uncertainty, completely independent of patent rights or their distribution.[315]

That is to say, "nanotechnologists" do not simply appear out of thin air. Nanotechnologists instead must be developed from other disciplines with other technological paradigms.[316] Like some other pioneering new technologies, nanotechnology was born of parallel but independent tracks of research in various fields. For instance, someone who started out as a materials scientist may create a nanotech advance with promising implications for medical research. To develop the invention further, the materials scientist will need to collaborate with an expert in medicine, biotechnology, or other fields, however, and the transaction costs of identifying and coordinating with others from different fields to collaborate on a new project can be steep. And even then, many factors create significant social barriers to the multidisciplinary cooperation necessary to design usable nanotechnology end products; institutional differences, lack of interdisciplinary standards and protocols, peer and institutional support, and other infrastructure, and even cultural differences between disciplines and the "inertia of disciplinary tradition," all can create a drag on the development process.[317] In these and other ways, the sociological aspects of technology development and any attendant "culture shock" may slow commercialization.

Perhaps because of nanotechnology's multidisciplinary nature and the need to unite specialists from many different areas, the majority of federal funding in nanotechnology thus far has been through government research laboratories rather than through university or private research facilities and thus falls under the provisions of the Stevenson-Wydler Act rather than Bayh-Dole.[318] The Stevenson-Wydler Act allows government-operated laboratories to enter into cooperative research and development agreements (CRADAs) with private contractors and to license, exclusively or nonexclusively, or even to assign title to, any resulting patents.[319] In this

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Journey on the Road to Translational Nanomedicine, 4 WIRES NANOMEDICINE & NANOBIOTECH. 366 (2012).

[315] Pedraza-Fariña, *supra* note 314, at 820; *see also* Wang, *supra* note 202, at 3497 (identifying the costs associated with intellectual migration).

[316] Ku, *supra* note 314, at 367.

[317] *Id*. at 374.

[318] MILLER ET AL., *supra* note 5, at 146; Wang, *supra* note 89, at 53.

[319] The Stevenson-Wydler Technology Innovation Act of 1980 originally directed federal agencies to transfer federally owned technology to both state and local governments, and to the private sector, but it was later amended and expanded to its present form. Wang, *supra* note 89, at 54–55; *see also* Arno, *supra* note 133, at 644 (referring to amendments to Federal Technology Transfer Act of 1986); Eisenberg, *supra* note 45, at 1707–08 (referring also to the National Technology Transfer and Advancement Act of 1995). Under Stevenson-Wydler, federal laboratory research must be transferred to private industry for commercialization, mostly through groups such as the Federal Laboratory Consortium for Technology

regard, CRADAs are effectively cost-sharing agreements, with the government contributing access to government equipment, facilities, and personnel rather than research funds.[320] The most relevant virtue of CRADAs, moreover, is that they can pool the expertise of federal laboratory researchers and private researchers from among a variety of disciplines—a point particularly important to multidisciplinary areas such as nanotechnology research.[321]

The federal government has also used public funds to establish other types of research centers that can help solve many of the problems of science-based technology development.[322] One such center devoted specifically to nanotechnology development is the Nanotechnology Characterization Laboratory (NCL) at the National Cancer Institute, a federally funded laboratory created as a collaborative effort among pharmaceutical companies, university researchers, and government agencies to offer free molecule-characterization services to universities and industrial nanodrug developers working in translational medicine.[323] The NCL thus serves not only to standardize the metrics for nanoparticle characterization but also to collect the necessary expertise from diverse institutions and disciplines, including biologists, chemists, toxicologists, immunologists, pathologists, technicians, and biomedical and chemical engineers, thus helping to overcome interdisciplinary gaps.[324] The NCL has the further advantage of helping to usher nanodrugs through the riskier intermediate development stages and to make those drugs more attractive to private investors.[325] Finally, the NCL is also a noncommercial organization that produces no scientific publications or intellectual property but is nonetheless more commercially oriented and flexible than any university could be.[326]

One unique and perhaps more significant aspect of nanotechnology that may be slowing down its development, according to nanotech expert Eric Drexler, is that government, private investors, and even scientists

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Transfer that are specially created to facilitate private acquisition of federal research. MILLER ET AL., *supra* note 5, at 146. Unlike research funded under the Bayh-Dole Act, however, federal laboratories typically retain patent rights over research created under a CRADA, Wang, *supra* note 89, at 63, but generally avoid granting exclusive licenses to their research whenever possible, MILLER ET AL., *supra* note 5, at 149.

[320] Wang, *supra* note 89, at 54–55.

[321] Frischmann, *supra* note 49, at 391–92; Vertinsky, *Making Knowledge*, *supra* note 283, at 760–65; Wang, *supra* note 89, at 69–70.

[322] *See, e.g.*, John C. Reed, *NCATS Could Mitigate Pharma Valley of Death: National Center for Advancing Translational Sciences Essential to Capitalize on Basic Research*, 31 GENETIC ENG'G & BIOTECH. NEWS, May 2011, 6–8, http://www.genengnews.com/gen-articles/ncatscould-mitigate-pharma-valley-of-death/3662/ [https://perma.cc/2KLX-BALB].

[323] Ku, *supra* note 314, *passim*.

[324] *See generally id.*

[325] Reed, *supra* note 322, at 7.

[326] Ku, *supra* note 314, *passim*.

themselves still do not fully appreciate what a true nanotechnology revolution would mean.[327] According to Drexler, the real definition of nanotechnology is a radical and comprehensive transformation in how things are manufactured, or what Drexler terms "atomically precise manufacturing" (APM).[328] Although closely related, the diffuse and largely piecemeal innovations that society currently identifies as nanotechnology have distracted from the bigger picture of what nanotechnology can offer and delayed realization of this promise as a result.[329]

Specifically, Drexler argues that although development efforts in nanotechnology thus far have led to the fabrication of new materials that exploit the unique phenomenon occurring at the nanoscopic level,[330] these advances have led mostly to use of the new nanomaterials as incremental improvements to existing technologies rather than fundamental changes in manufacturing methods or APM.[331] As one science historian put it, nanotechnology "consists of different, largely 'mono-disciplinary fields' which are rather unrelated to each other and which hardly share more than the "nano" prefix."[332] Drexler contends that nanotechnology is not just about improving existing technologies, however, but rather about the profound change in manufacturing globally that would come from APM.[333] Although a more scientific explanation of APM is obviously beyond the scope of the discussion here, atomically precise manufacturing is in many ways analogous to 3D printing or intracellular protein synthesis in that APM allows fabrication of an infinite variety of materials and objects through meticulous, sequential assembly of individual molecules of common elements.[334] Atomically precise manufacturing allows less expensive, environmentally cleaner, and thus "ultra-efficient" industrial-level production to take place not just in factories but also on desktops or anywhere else.[335] Atomically precise manufacturing will revolutionize fabrication processes because APM uses less raw material to create objects

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[327] DREXLER, *supra* note 201, at xi.

[328] *Id.* at x, xii.

[329] *Id.* at xi, 121, 178, 195–96.

[330] *Id.* at xi.

[331] *Id.* at ix, 198; MILLER ET AL., *supra* note 5, at 151–52; Akhtar, *supra* note 6, at 134; *see also* Wasson, *supra* note 38, at 10 n.6 (explaining that nanotechnology has "focused on enhancing traditional products").

[332] Ku, *supra* note 314, at 367.

[333] DREXLER, *supra* note 201, at xi.

[334] PRODUCTIVE NANOSYSTEMS: A TECHNOLOGY ROADMAP v, 4 (K. Eric Drexler et al. eds., 2007) [hereinafter ROADMAP]; Bruce Dorminey, *Nanotechnology's Revolutionary Next Phase*, FORBES (Feb. 26, 2013), http://www.forbes.com/sites/brucedorminey/2013/02/26/nanotechnologys-civilization-changing-revolutionary-next-phase/; *Productive Nanosystems: From Molecules to Superproducts*, NANO WERK, http://www.nanowerk.com/nanotechnology/videos/Productive_nanosystems_From_molecules_to_superproducts.php [https://perma.cc/76LJ-LYLV] (last visited Nov. 15, 2016).

[335] DREXLER, *supra* note 201, at ix–xii.

that are stronger and yet lighter, thereby reducing both shipping costs and energy costs.[336] It is perhaps this kind of technologically brave new world that many predicted nanotechnology would bring and that critics worry that the Bayh-Dole Act has helped stymy.

And in fact, progress in APM has not been as rapid as Drexler and others had hoped,[337] but Drexler attributes the logjam to a lack of investment and focus, not to upstream patenting.[338] APM does exist to a limited extent in some isolated fields, but systemic changes in manufacturing technologies have yet to emerge.[339] According to Drexler, this is due in part to the fact that nanotechnology development continues to be scattered among divergent scientific disciplines, a cohesive vision of APM is still lacking.[340] Government agencies and other investors have focused instead on the development of nanoparticles and other lower hanging fruit with more readily attainable and yet less impressive returns.[341]

6. *Safety Fears*

A different risk that some nanotechnology enthusiasts mention as a problem for nanotech development is the health, environmental, and other dangers that nanotech applications may pose. Nanotechnology's relative unfamiliarity has provoked the same kinds of fears that have beset research in other research-based fields such as pharmaceuticals, genetically modified organisms, cloning, and human embryonic stem cells.[342] And because nanotech is such a uniquely cross-disciplinary area of research, it has applications and therefore potential safety ramifications in a number of heavily regulated fields.[343] In fact, to avoid triggering governmental regulatory review or public apprehension, some companies may try to keep their products "below the radar" by failing to identify products containing nanomaterials.[344] More importantly, concerns about possible regulatory barriers have also dampened investment in nanotech development: the specter of regulatory restrictions and potential liability for consumer, environmental, or other harms create additional uncertainties that yet further

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[336] *Id*. at 162–63.

[337] *Id*. at 195.

[338] *Id*. at 178.

[339] *See* ROADMAP, *supra* note 334, at v, 4 (listing technologies using living tissue and scanning probe manipulation on crystal surfaces as examples of currently employed APM).

[340] DREXLER, *supra* note 201, at 121.

[341] *Id*. at 178, 195.

[342] *See* SOCIETAL IMPLICATIONS, *supra* note 20, at 203; Ron A. Bouchard, *Balancing Public and Private Interests in the Commercialization of Publicly Funded Medical Research: Is There a Role for Compulsory Government Royalty Fees?*, 13 B.U. J. SCI. & TECH. L. 120, 127–28 (2007); Gary E. Marchant et al., *What Does the History of Technology Regulation Teach Us About Nano Oversight?*, 37 J.L. MED. & ETHICS 724, 727–28 (2009) (noting that society often has strong social and ethical concerns about emerging technologies such as nanotechnology).

[343] Marchant, *supra* note 342, at 724.

[344] Wolfe, *supra* note 37.

deter private and even government funding in nanotech R&D.[345] Public fears about nanotechnology have also negatively influenced enthusiasm for the field, and therefore its success.[346]

Some of the health and environmental concerns about nanotechnology are well-founded. Graphene particles, for example, may present some risk of respiratory damage, although review of graphene is ongoing.[347] Similarly, carbon nanotubes and buckyballs may be toxic when used in humans, whereas dendrimers may be a less toxic alternative for use in living organisms.[348] Particular instances of environmental and health dangers have apparently led to overgeneralization, however, and are leading some commentators to worry that the toxicity of some nanomaterials has created a stigma that encompasses all of nanotechnology in one stroke of the brush.[349]

And the science-fiction-level hype around nanotechnology has indeed led to popular but distorted fears about its safety. Some have even drawn on science fiction to dream up sensationalist, apocalyptic scenarios for how nanotechnology could herald the end of the world as we know it. Perhaps the most infamous of this latter category is the late Michael Crichton's "gray goo:" self-replicating nanobots that escape the laboratory and run amok, devouring the entire biosphere and turning it into copies of themselves.[350]

Such a nano-apocalypse is unlikely and perhaps even scientifically impossible,[351] but whether outlandish or reasonable, these fears have been enough to spur calls for caution in and even a moratorium on nanotechnology development until further research can be done on the potential safety impact of the field and appropriate regulations can be put in place.[352] A 2000 article by Bill Joy of Sun Microsystems even went so far as to call for a ban on nanotechnology because of its perceived perils to human health and safety.[353] Whether such moratoria or outright bans are warranted and whether nanotechnology threatens health and environmental harms significantly greater than those in other technologies are open questions.[354]

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[345] Allen, *supra* note 2; Lee, *supra* note 175, at 323; Schmoch & Thielmann, *supra* note 140, at 133.

[346] Marchant, *supra* note 342, at 725.

[347] Philip Shapira et al., *Early Patterns of Commercial Activity in Graphene*, 14 J. NANOPART. RES. 811, 812 (2012).

[348] Lee, *supra* note 175, at 323.

[349] *See id.*; Schmoch & Thielmann, *supra* note 140, at 133 (noting that lack of conclusive toxicity studies could give nanotech a negative image and hinder its commercialization).

[350] *See* DREXLER, *supra* note 6, at 172–73; Bawa, *supra* note 3, at 703; Glenn Harlan Reynolds, *Nanotechnology and Regulatory Policy: Three Futures*, 17 HARV. J.L. & TECH. 179, 188 (2003).

[351] *See* Fiedler & Reynolds, *supra* note 6, at 605–06 (stating that nanorobot existence has a science fiction resonance, but "the reality is less dramatic").

[352] *See* Bawa, *supra* note 3, at 703; Rao, *supra* note 63, at 861–62.

[353] Bill Joy, *Why the Future Doesn't Need Us*, WIRED (Apr. 1, 2000, 12:00 PM), https://www.wired.com/2000/04/joy-2/ [https://perma.cc/D54F-XBDP].

[354] *See* Marchant et al., *supra* note 342, at 726.

What is clear, however, is that apprehension about nanotechnology's potential hazards have helped obstruct progress in the field.

C. *So Why Bother Patenting Science-Based Technologies at All?*

The discussion above demonstrates that to attribute the lack of progress in nanotechnology development solely or even primarily to the Bayh-Dole Act and upstream patenting, university patenting, or the combination thereof overlooks a whole host of other factors that play a much more significant role in science-based technologies. This is not to say upstream research patenting by universities is *entirely* inconsequential. On the one hand, the costs of licensing upstream university patents may at the margin occasionally tip the scales toward nondevelopment, as Professor Lemley and others have argued.[355] Alternatively, as this author has argued, upstream patents may on very rare occasions facilitate downstream development.[356] The vast majority of upstream patents held by universities in science-based technologies, however, are simply irrelevant either as a handicap or as a help in downstream development.

The question then becomes, why would universities take the trouble to patent their research at all? And why did Congress believe it to be a good idea to pass the Bayh-Dole Act and to encourage universities to patent their research? If patents on basic university research have so little effect on downstream commercialization of that research, at the very least universities are simply wasting their already limited resources in bothering to file and prosecute patent applications.

And in fact, universities do not patent the vast majority of their faculties' research, as noted above.[357] Very little of university research is eligible for patenting, an even smaller percentage is worth the costs of patenting, and almost no university research yields profits from patent licensing.[358] As a result, most university TTOs operate at a loss; again, patenting and licensing university research is a money-losing proposition for all but the fortunate few.[359]

That being said, not all university patents and university research fall into the category of basic upstream research, and not all university research

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[355] *See supra* Section II.

[356] Morris, *supra* note 127, Part I; Emily Michiko Morris, *Flexing Bayh-Dole* (unpublished manuscript) (on file with author).

[357] *See supra* notes 177–79 and accompanying text.

[358] *Id.*

[359] *See* Greenbaum, *supra* note 68, at 331, 358–59 (citing a lack of interest in scientists who wish to develop university-owned inventions because almost none of university research yields profits from licensing); Thomas K. Grose, *A Challenging Matchup*, 15 AM. SOC'Y ENG'G EDUC. PRISM 20 (2006) (discussing that companies complain that too many university technology transfer administrators have an "unrealistic notion that they can make money off of all research").

is performed solely for the sake of knowledge. As a first matter, patents on university inventions in applied rather than basic research, such as university research in engineering, applied sciences, and some areas of biotechnology, require fewer and less risky additional steps to achieve commercialization and therefore are easier to license and higher in commercial value.[360] And even in the basic sciences, patented university research often serves dual roles both as upstream building blocks for downstream development and as "completed" products ready for use as commercially available research tools.[361] Second, private firms that sponsor university research will often ask the university to patent any consequent inventions and to grant these firms exclusive licenses to those patents.[362] Patents therefore can be worthwhile for the small percentage of university research conducted under private sponsorship agreements.[363] Third, universities may be willing to invest in patenting because of the reputational benefits patents provide,[364] although publication and other less costly signals of productivity may serve just as well.[365]

But as for why universities patent research outside of these rather narrow categories, the most likely explanation is the "home run mentality" of some university TTOs and even faculty.[366] Because of what has now become the near-mythological status of the patents on Harvard's OncoMouse and the University of Wisconsin's human stem cell technology, whose unusually high commercial value garnered millions in revenue for their respective universities,[367] many TTOs have come to regard university research patents as a sort of lottery ticket through which the TTOs hope eventually to hit it big on the one blockbuster patent that will earn untold fame and fortune for

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[360] David C. Mowery & Bhaven N. Sampat, *The Bayh-Dole Act of 1980 and University-Industry Technology Transfer: A Model for Other OECD Governments?*, 30 J. TECH. TRANSFER 115, 116 (2005).

[361] *See* Dreyfuss, *supra* note 128, at 468.

[362] Jensen & Thursby, *supra* note 97, at 252. Although Bayh-Dole does not allow universities to assign the rights to their patents ahead of time if the covered research is also funded in part through federal funds (because Bayh-Dole reserves the government's right to veto such transfers). Sean M. O'Connor, *Intellectual Property Rights and Stem Cell Research: Who Owns the Medical Breakthroughs?*, 39 NEW ENG. L. REV. 665, 669 (2005). The potential to patent and exclusively license the research is made clear under the Act. *Id.* at 687. When it comes to university patents, as opposed to other forms of university technology transfer, private firms also tend to be more interested in readily commercializable, applied research. Wesley M. Cohen et al., *Links and Impacts: The Influence of Public Research on Industrial R&D*, 48 MGMT. SCI. 1, 16–17 (2002); Fini & Lacetera, *supra* note 95, at 10.

[363] Eisenberg, *supra* note 45, at 1700; Nelson, *supra* note 103, at 463.

[364] *See, e.g.*, Lee, *supra* note 128, at 676 ("Furthermore, centralized government registration of patents helps establish scientific consensus."); Love, *supra* note 208, at 332–34 (presenting research that more than a third of the respondents reported that patents enhanced their universities' and their own reputations).

[365] Adelman, *supra* note 171, at 127; Kesan, *supra* note 160, at 2184.

[366] Robert E. Litan et al., *Commercializing University Innovations: Alternative Approaches*, 8 INNOVATION POL'Y & ECON. 31, 43–44 (2007).

[367] *Cf.* Walsh et al., *supra* note 149, at 296–309 (discussing the commercial success of these patents).

the university and the inventing faculty.[368] This home-run mindset has led TTOs to hold some arguably unrealistic expectations about their patents' value and to focus too much of their limited resources on pursuing patents on the technologies with the greatest perceived blockbuster potential.[369] Because of the uncertainty inherent in science-based technologies, however, the eventual commercial value of upstream patents in these fields is highly variable and difficult to predict,[370] much like a lottery ticket. Not surprisingly, the home-run mentality has caused universities to invest in filing and accumulating patents that ultimately have little to no commercial value.

It is therefore not surprising that, when stuck with patents that turn out to have no market value, universities often decide not to pay maintenance fees for the patents and allow them to fall into the public domain instead.[371] Professor Kimberly Moore's study of patent-renewal rates and maintenance-fee payments provides corroborative evidence, documenting that early-stage patents are more likely to lapse for nonpayment of maintenance fees where the underlying technologies' development costs are high and where private industry has shown little interest in the technologies.[372] And recently, Pennsylvania State University went so far as to use an auction of fifty-nine of its unlicensed engineering patent portfolios to gather useful information on what types of patents were no longer worth the cost of paying maintenance fees.[373] Thus, although university TTOs may in the short term be overly optimistic about patenting their research, in the longer term universities seem to recognize that most of those patents are pointless to maintain.

CONCLUSION

Nanotechnology is promised to be the next technological revolution, but

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[368] Bagley, *supra* note 207, at 259; Greenbaum, *supra* note 68, at 360.

[369] *See, e.g.*, Grose, *supra* note 359, at 20; Litan et al., *supra* note 366, at 43.

[370] *See* Kimberly A. Moore, *Worthless Patents*, 20 BERKELEY TECH. L.J. 1521, 1544, 1547–48 (2005).

[371] *Id.* at 1525 (surveying payment of maintenance fees on patents issued in 1991). Increasing maintenance fees must be paid at 3.5 years, 7.5 years, and 11.5 years after a patent is issued; failure to pay any of these fees leads to patent expiration in six months. *Id.* at 1525.

[372] *Id.* at 1534, 1544, 1547–48 (noting this phenomenon in biotech, pharmaceutical and chemical fields).

[373] Goldie Blumenstyk, *Penn State's Patent Auction Produces More Lessons Than Revenue*, CHRONICLE OF HIGHER EDUC. (May 1, 2014), http://chronicle.com/blogs/bottomline/penn-states-patent-auction-produces-more-lessons-than-revenue/ [https://perma.cc/2456-MCLU]. One of the reasons that Penn State sold so few patents may have been the restrictions that the university placed on the auction to prevent so-called patent trolls—nonpracticing entities that use patents to extract rents from unknowing infringers—from acquiring the patents. Neil Kane, *Patents for Sale: How to Separate the Valuable from the Worthless*, FORBES (May 22, 2014), http://www.forbes.com/sites/neilkane/2014/05/22/a-modest-proposal-for-licensing-patents/; *cf.* NRC, *supra* note 224, at 6–7 (advocating against university patent sales to patent aggregators and other nonpracticing entities).

development in the field has been slower than many had hoped. As Professor Siva Vaidhyanathan observed in 2005, "right now nanotechnology is more science than technology (some would argue more science fiction than science)."[374] The question is, why? Given the relatively high levels of patenting on university research in the area, it is understandable that Professor Lemley and several other commentators suspect that these patents are hindering nanotech's development transfer from university research to commercialized application. Translating research and knowledge into useable technologies depends on more than just intellectual property rights,[375] and the importance of patents versus other methods of technology transfer varies widely from case to case.[376] For nanotechnology, many if not most of university patents will have little effect on future nanotechnology development. Although some very small percentage of nanotech development may experience anticommons or other holdup problems because of upstream university patenting, development of other applications may be experiencing delays that have little to do with patenting ownership patterns or the degree of patenting on upstream research.

First, with regard to the risk of patent-induced holdup problems: a patent that covers "basic" or "upstream" research will not necessarily have enough preemptive breadth to hold up downstream development.[377] Many upstream nanotech patents may resemble gene sequence patents in that they require downstream work to be of commercial value but still are narrow enough that they can be easily designed around using meaningful substitutes. Such upstream but substitutable patents are unlikely to cause holdup problems.[378] Unless a patent covers one of the few foundational or "common-method research tools" and unless those patents are not licensed freely, little in the way of hold up is likely to occur.[379]

As compared to patents, moreover, other technological, economic, and sociologic issues may be much more significant drags on technological development than commonly realized. Nonpatent exclusivities, as well as risk aversion, lack of funding, and information gaps, play significant roles in the development of science-based technologies such as nanotech. Where access to research materials and tools, tacit knowledge, lack of private capital, and lack of public support are more rate-limiting than patents, as appears to be the case in most of nanotechnology development at this point in time, patents are for most intents and purposes simply irrelevant. Likewise, the overall effect of patenting depends greatly on the inherent

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[374] Vaidhyanathan, *supra* note 3, at 232.

[375] NRC, *supra* note 224, at 2.

[376] Cahoy & Glenna, *supra* note 226, at 433; Jeannette Colyvas et al., *How Do University Inventions Get into Practice?*, 48 MGMT. SCI. 61, 62 (2002).

[377] *See* Adelman, *supra* note 171, at 133.

[378] *See* Kieff, *supra* note 130, at 730–31 (noting that the availability of market alternatives limits patent holders' power to set a price).

[379] Adelman, *supra* note 171, at 139.

uncertainties of and the time and expense necessary to developing downstream applications. Especially in revolutionary new fields like nanotechnology, the more time- and resource-intensive downstream development becomes, the more uncertainty attaches, and the less likely it is that upstream university patents will be important to the outcome.