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INTRODUCTION

When you were in school, when did you learn the most? When your teacher pushed you with high expectations and you knew you were competing with other students, or when you took a pass-fail course where attendance was optional? When do you think athletes get into the best shape? When they are competing against others and being pushed by their coach, or when they work out alone with no clear competition in mind?

In the same way, when do you think inventors and firms are the most competitive and innovative? When they are being pushed by their competitors to develop the best product, or when they can rest behind a twenty-year exclusivity provided by a patent?

At first, the answer seems clear: The firm with the patent would be complacent and less productive than the firm that must fight hard to out-innovate its competitors continually.[1] Yet, the

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1 *See* Robert P. Merges & Richard R. Nelson, *On the Complex Economics of Patent Scope*, 90 COLUM. L. REV. 839, 872 & n.141 (1990) (describing historical instances of entrepreneurs that quickly turned into lazy established firms); Andreas Panagopoulos, *The Effect of IP Protection on Radical and Incremental Innovation*, 2 J. KNOWLEDGE ECON. 393, 394–95 (2011) (noting that strong patents can negatively affect commercialization rates and stating that "lack of competition can lead an innovator to rest on her laurels failing to advance a valuable and radical innovation further"). This intuition fits with sociological theory, as well. *See* Stephanie Plamondon Bair, *The Psychology of Patent Protection*, 48 CONN. L. REV. 297, 325–26 (2015) (applying Parkinson's law, which states that work expands to fill the time

patent system arose, in large part, to address an apparent flaw in this line of thinking. Namely, since the first innovator must sink large amounts of capital into researching and developing an innovation and follow-on competitors do not, the first innovator will lose in the marketplace because it cannot charge a price high enough to recoup its research and development ("R&D") costs.[2] The patent system purports to provide innovators with the incentive to invent and disclose those inventions by granting a twenty-year exclusive right to practice the innovation.[3]

In addition, scholars have articulated other economic justifications for the patent system.[4] For example, Edmund Kitch famously proposed that patents provide a "prospect" function, under which broad patents provide owners "an incentive to make investments to maximize the value of the patent without fear that the fruits of the investment will produce unpatentable information appropriable by competitors."[5] The prospect theory thus seeks to protect postinvention innovation expenditures by strengthening patents—such as by lengthening patent terms or broadening patent coverage.

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allotted for it, to patent law to show that a twenty-year patent term will sometimes result in a slow pace of innovation).

[2] Citations for the incentive theory are legion. *See, e.g.*, David S. Olson, *Taking the Utilitarian Basis for Patent Law Seriously: The Case for Restricting Patentable Subject Matter*, 82 TEMP. L. REV. 181, 182–83 (2009) (stating that without patent rights, "copycats will . . . drive down prices below the price at which the inventor can recoup her research and development costs").

[3] *E.g.*, SUBCOMM. ON PATENTS, TRADEMARKS, AND COPYRIGHTS OF THE S. COMM. ON THE JUDICIARY, 85TH CONG., AN ECONOMIC REVIEW OF THE PATENT SYSTEM 33 (Comm. Print 1958) (Fritz Machlup) [hereinafter Machlup, PATENT SYSTEM] ("The thesis that the patent system may produce effective profit incentives for inventive activity and thereby promote progress in the technical arts is widely accepted."). Indeed, the incentive theory undergirds the intellectual property clause in the U.S. Constitution. U.S. CONST. art. I, § 8, cl. 8 ("To promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries . . . .").

[4] Scholars also propound noneconomic justifications for the patent system, including natural-rights and personhood-based theories. *See, e.g.*, Justin Hughes, *The Philosophy of Intellectual Property*, 77 GEO. L.J. 287, 330 (1988). Given the utilitarian focus of the U.S. Constitution, these theories command less attention. The labor-desert theory is briefly discussed in Part III.

[5] Edmund W. Kitch, *The Nature and Function of the Patent System*, 20 J.L. & ECON. 265, 276 (1977).

Regardless of the theory to which one ascribes—the incentive to invent view, the prospect view, or variants thereof—the patent system unfortunately imposes key costs on society. First, by giving an exclusive right to its owner to make, use, sell, and offer to sell the invention, a patent raises the potential for the inventor to sell the invention at a price higher than what it would command in a perfectly competitive market.[6] To the extent there are no reasonable substitutes, a patent holder can charge a higher monopoly price for the invention and thus make more profit per item sold. The increased price forces some purchasers out of the market for the item, creating a deadweight loss.[7]

Second, the patent system can also burden society by impeding follow-on technology.[8] Technology creation is cumulative; inventors build on the inventions of yesterday to bring forth new inventions.[9] Patents can discourage follow-on research by preventing the inventor of an improvement from commercializing it to the extent that it infringes the first patent.[10] The longer technology remains patented, the slower the cumulative research advances that build upon it will be.

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[6] *See* WILLIAM M. LANDES & RICHARD A. POSNER, THE ECONOMIC STRUCTURE OF INTELLECTUAL PROPERTY LAW 17, 304 (2003).

[7] *See id.* at 74–76. A second form of deadweight loss, duplicative research costs in a race to be first to obtain the patent, also exists. *See, e.g.*, Merges & Nelson, *supra* note 1, at 870–71. Generally, the stronger the patent award, the more duplicative research costs will occur as everyone races harder. Of course, even in the absence of patents, firms will sometimes race to be the first to invent or to reach the market.

[8] Merges & Nelson, *supra* note 1, at 870 ("[B]road patents could discourage much useful research."). Patents can also impede the dissemination of technology where the patentee is unable to effectively disseminate the patented technology and is unable to partner with those who could. Ted Sichelman, *Commercializing Patents*, 62 STAN. L. REV. 341, 368–69 (2010).

[9] Suzanne Scotchmer, *Standing on the Shoulders of Giants: Cumulative Research and the Patent Law*, 5 J. ECON. PERSP. 29, 29 (1991).

[10] Of course, the follow-on researcher can nevertheless patent its improvement, thereby blocking the broad patent holder from practicing the improvement. Mark A. Lemley, *The Economics of Improvement in Intellectual Property Law*, 75 TEX. L. REV. 989, 1047 (1997) (noting that improvements can be separately patented). But the party with the later patent would not be able to practice its invention without a license from the first patentee, which can be difficult to obtain); *see, e.g.*, Robert Merges, *Intellectual Property Rights and Bargaining Breakdown: The Case of Blocking Patents*, 62 TENN. L. REV. 75, 80–82 (1994).

Although there are other costs to the patent system, the harms from monopoly pricing and follow-on impedance represent two of the most prominent. And, in general, the stronger the patent rights, the worse the harms. Thus, the prospect theory's predilection for stronger patents would increase the patent system's costs from higher prices and impediments to follow-on inventions,[11] as well as encourage more complacency.[12]

A perfect patent system would minimize costs by matching exactly the incentive granted for each innovation to the size of the R&D costs for that innovation and by taking into account follow-on technology concerns. Thus, an innovation that was relatively inexpensive to develop, such as the Post-it® Note,[13] might need a small incentive, whereas an innovation requiring large R&D costs, such as a prescription drug, might need a large incentive. Despite the intuitiveness of this observation and the multitude of articles analyzing it,[14] the patent system is largely a one-size-fits-all endeavor. The reasons for this model include the political friction against change and the belief that the administrative costs of tailoring a patent system to the costs of each innovation, or innovation type, are so great that they outweigh the benefits.[15]

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[11] Sichelman, *supra* note 8, at 380. A robust licensing market can lessen the impediments to follow-on innovation, but this is easier said than accomplished. *Id.* at 369, 384–85; *see also* Merges & Nelson, *supra* note 1, at 874 (noting the steep costs accompanying technology licensing).

[12] Merges & Nelson, *supra* note 1, at 873–74 (critiquing the prospect theory as encouraging complacency).

[13] Interestingly, the Post-it® Note was a combination of basic research, serendipitous discovery, and a "eureka" moment. *History Timeline: Post-it® Note Notes*, POST-IT BRAND, http://www.post-it.com/3M/en_US/post-it/contact-us/about-us/ (last visited Mar. 31, 2016). A 3M scientist accidentally discovered the adhesive while doing other research but could find no use for it. *Id.* Several years later, a second 3M scientist had the idea to use the adhesive to help keep his bookmark in his hymnal and quickly realized the vast application for the adhesive. *Id.*

[14] *E.g.*, Michael W. Carroll, *One for All: The Problem of Uniformity Cost in Intellectual Property Law*, 55 AM. U. L. REV. 845, 847–49 (2006); Eric E. Johnson, *Calibrating Patent Lifetimes*, 22 SANTA CLARA COMPUTER & HIGH TECH. L.J. 269, 269 (2006); Amir H. Khoury, *Differential Patent Terms and the Commercial Capacity of Innovation*, 18 TEX. INTELL. PROP. L.J. 373, 374 (2010); Benjamin N. Roin, *The Case for Tailoring Patent Awards Based on Time-to-Market*, 61 UCLA L. REV. 672, 672 (2014).

[15] *See, e.g.*, ADAM B. JAFFE & JOSH LERNER, INNOVATION AND ITS DISCONTENTS: HOW OUR BROKEN PATENT SYSTEM IS ENDANGERING INNOVATION AND PROGRESS, AND WHAT TO DO ABOUT IT 203–04 (2004) (expressing concerns about tailoring patents); NAT'L RESEARCH COUNCIL, A PATENT SYSTEM FOR THE 21ST CENTURY 81

Further, few seem happy with the patent system. A survey of literature examining the patent system demonstrates a popular belief that something is dreadfully wrong with it.[16] Almost everyone seems to agree something is wrong, but no one can agree on a remedy. How can so many people disagree so widely? The truth is that the absolute values of the patent system's costs and benefits are unknown.[17] Although we do not know the exact costs and benefits of patents, scholars have carried on a long tradition of debating whether we should strengthen or weaken the patent system.[18] Some even advocate for abolishing the patent system altogether.[19]

This Article contributes to the patent debate by observing that new and emerging technologies are radically altering the relative costs and benefits of the patent system. Although analysts cannot measure the patent system's numerous absolute costs and benefits, this Article demonstrates that new and emerging technologies are significantly reducing the research, development, and commercialization costs ("innovation costs") that are used by adherents to the incentive and prospect theories to justify the patent system's existence. All things being equal, if

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(Stephen A. Merrill. et al. eds., 2004) (arguing that the patent system should remain unitary).

[16] *See generally* MICHELE BOLDRIN & DAVID K. LEVINE, AGAINST INTELLECTUAL MONOPOLY (2008); DAN L. BURK & MARK A. LEMLEY, THE PATENT CRISIS AND HOW THE COURTS CAN SOLVE IT (2009); JAFFE & LERNER, *supra* note 15; NAT'L RESEARCH COUNCIL, *supra* note 15.

[17] Machlup, PATENT SYSTEM, *supra* note 3, at 80 ("If we did not have a patent system, it would be irresponsible, on the basis of our present knowledge of its economic consequences, to recommend instituting one. But since we have had a patent system for a long time, it would be irresponsible, on the basis of our present knowledge, to recommend abolishing it."). Though we have progressed greatly in our understanding of the patent system and innovation since Machlup's statement, we still do not understand fully the economic effects of the patent system. ROBERT P. MERGES, JUSTIFYING INTELLECTUAL PROPERTY 3 (2011) ("The sheer practical difficulty of measuring or approximating all the variables involved means that the utilitarian program will always be at best aspirational.").

[18] *See, e.g.*, *American Patent System: Hearings Before the Subcomm. on Patents, Trademarks, and Copyrights of the S. Comm. on the Judiciary*, 84th Cong. 116 (1955) (statement of Judge Learned Hand) ("[T]here are two schools and the one school beats the air and says without the patent system the whole of American industry would never have been developed . . . and the other says it is nothing but a beastly method . . . . No one really knows. Each side is beating the air.").

[19] BOLDRIN & LEVINE, *supra* note 16, at 243–44 ("[E]ffectively abolishing intellectual property protection is the only socially responsible thing to do."); JAFFE & LERNER, *supra* note 15, at 35.

innovation costs have decreased, and will continue to decrease significantly, the relative need for the patent system has decreased and will continue to decrease.[20] Thus, this Article argues that patents should be weakened significantly—by at least twenty-five to fifty percent.

To support this claim, this Article takes an interdisciplinary approach out of appreciation for the fact that innovation spans many disciplines:[21] Two of the authors are scientists with extensive expertise in three-dimensional printing, and the remaining author is a law professor who is an expert on patent law. Altogether, this Article offers a thorough catalog of new and emerging technologies and their effects, both general and specific, on innovation costs and the patent system.[22]

This Article is not the first to recognize the profound effect new technologies are having on the intellectual property system.[23] In his article, *IP in a World Without Scarcity*, Professor Mark Lemley looks into the future and sees a world "that

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[20] It is true that many technological breakthroughs in the last centuries have lowered some costs of innovation. Steam engines and internal combustion engines, among other technologies, made certain things feasible that were otherwise not. Yet this just demonstrates that the case for weakening patent rights has been building over time. What makes many of the technologies this Article describes different from many previous advances, however, is their accessibility to nonexperts, their low cost, and their flexibility. For example, teenagers can work with and harness the Internet and 3D printing in ways that they cannot with internal combustion engines.

[21] OXFORD UNIV. PRESS, THE OXFORD HANDBOOK OF INNOVATION 3 (Jan Fagerberg et al. eds., 2005) ("[N]o single discipline deals with all aspects of innovation. Hence, to get a comprehensive overview, it is necessary to combine insights from several disciplines.").

[22] This Article's analysis is thorough, but by nature of space constraints, cannot be exhaustive. The analysis invites additional research from patent experts, technology specialists, and empiricists, among others.

[23] Various commentators have discussed how 3D printing will impact the law, but have not recommended significantly weakening patents. Deven R. Desai, *The New Steam: On Digitization, Decentralization, and Disruption*, 65 HASTINGS L.J. 1469, 1472–73, 1475 (2014); Deven R. Desai & Gerard N. Magliocca, *Patents, Meet Napster: 3D Printing and the Digitization of Things*, 102 GEO. L.J. 1691 (2014) (discussing the potential impacts of 3D printing on the future of patent, copyright, and trademark law); Nora Freeman Engstrom, *3-D Printing and Product Liability: Identifying the Obstacles*, 162 U. PA. L. REV. ONLINE 35, 36 (2013) (discussing the possible impact of 3D printing on the future of products liability law); Lucas Osborn, *Intellectual Property's Digital Future*, *in* RESEARCH HANDBOOK ON DIGITAL TRANSFORMATIONS (F. Xavier Olleros & Majlinda Zhegu eds., forthcoming 2016); Lucas S. Osborn, *Of PhDs, Pirates, and the Public: Three-Dimensional Printing Technology and the Arts*, 1 TEX. A&M L. REV. 811, 811 (2014); Lucas S. Osborn, *Regulating Three-Dimensional Printing: The Converging Worlds of Bits and Atoms*, 51 SAN DIEGO L. REV. 553, 582–92 (2014).

promises to end scarcity as we know it for a wide variety of goods."[24] The thrust of Professor Lemley's article is in line with this Article, which agrees that intellectual property protection will someday be the exception, not the rule. But unlike Professor Lemley, who focuses on that future and finds it "hard to [make] immediate policy prescriptions,"[25] this Article focuses on the present and provides suggestions for this transitional period between the status quo and whatever the future may bring.

In Part I, this Article introduces the new and emerging technologies, including the Internet,[26] cloud computing, three-dimensional ("3D") printing,[27] and synthetic biology, which will bring this radical change. Part II provides an overview of the innovation cycle, including the stages of basic research, inventing and prototyping, product development, marketing, and distribution. It also describes, in detail, how these new technologies are dramatically lowering the costs and risks of all stages in the innovation cycle.

Part III considers how lawmakers might adapt patent law to account for the new age of innovation and its lower costs of innovation. This Article explores both the magnitude of the change and the method by which that change should be accomplished; specifically, it analyzes various factors that might affect the magnitude of the change to patent strength, such as nonmonetary incentives to innovate, decreased costs of copying innovations, and concerns about U.S. companies' competitiveness in a global marketplace. After considering these factors, this Article recommends that lawmakers weaken patents by at least twenty-five to fifty percent. Such a change would not only account for decreased costs of innovation, but also would be large enough for the change to be unequivocally felt and studied. To accomplish this reduction in patent strength this Article explores shortening the patent term, but with the understanding that to do so would be politically difficult. Thus, it recommends dramatically raising patent maintenance and renewal fees for

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[24] Mark A. Lemley, *IP in a World Without Scarcity*, 90 N.Y.U. L. REV. 460, 461 (2015).

[25] *Id.* at 507.

[26] The Internet may not feel new, but the authors can easily remember trying to access it with dial-up modems.

[27] Two of the authors are experts in 3D printing technology and have conducted countless experiments and built numerous products with 3D printers.

the end portion of patents' lives. Finally, this Article also briefly explores doctrinal changes that could weaken patents in specific technology sectors and explain why we consider them a second-best option.

I. KEY EMERGING TECHNOLOGIES

Though it is no longer new, the Internet represents one of the key technologies driving change. Additionally, the ever-falling cost of computer power and memory represents a second key driver, producing smart phones with more power than the supercomputers of previous generations. At least three new technologies will combine with the Internet and fast, cheap computers to profoundly impact the innovation cycle for many goods.

A. *Three-Dimensional Printing*

Three-dimensional ("3D") printing, or additive manufacturing, essentially produces a part layer-by-layer. A computer-generated model of the part is sliced into discrete layers and converted into controls for the printer, similar to a computer converting a word document into computer code for a two-dimensional ("2D") printer. 3D printing requires energy, typically in the form of heat or light radiation, to effect a phase change in a print material one layer at a time.

3D printing technology has a short but rich history of rapid technological development, and the speed of development is increasing exponentially as key patents expire. Over a period of approximately thirty years, 3D printing has been invented, developed by major corporations, and eventually brought to the average consumer. Following early research, Charles Hull invented 3D printing in 1983.[28] He invented a stereolithography process and established the first commercial 3D printing company, 3D Systems.[29] Following this, the 1980s included massive amounts of research related to additive manufacturing.

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[28] *30 Years of Innovation: The Journey of a Lifetime*, 3D SYSTEMS, http://www.3dsystems.com/30-years-innovation (last visited Apr. 1, 2016).

[29] Terry Wohlers & Tim Gornet, *History of Additive Manufacturing*, WOHLERS REPORT 2014, at 29 (2014), http://wohlersassociates.com/history2014.pdf.

The 1990s saw continued growth and development.[30] Advances included the debut and commercialization of several 3D printing methods, including fused filament fabrication, selective laser sintering, and material jetting, discussed below. Many industries began using stereolithography, such as the custom biomedical implant industry[31] and the jewelry industry.[32] Due to printing costs, the technology was limited to large corporations and specialized industries. In the 2000s, the technology continued to advance. Since 2010, 3D printing milestones include a printed car,[33] aircraft,[34] and liver and artificial tissue containing blood vessels.[35]

Fused filament fabrication promised to be inexpensive enough for average consumers to use. As key patents covering it were about to expire, the pace of progress for this technology quickened dramatically. In 2005, the University of Bath launched the open-source RepRap project with the goal of developing an open-source fused filament fabricator that is also a self-replicating rapid-prototyper.[36] In 2007, the project's first iteration, the Darwin, was released, spawning a marked change in development of 3D printing technology.[37] The RepRap development community is made of hundreds of developers all over the world sharing designs.[38]

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[30] *Id.* at 1–3.

[31] Rapid, Customized Bone Prosthesis, U.S. Patent No. 5,370,692 (filed Aug. 14, 1992).

[32] Wohlers & Gornet, *supra* note 29, at 2.

[33] Darren Quick, *The Urbee Hybrid: The World's First 3D Printed Car*, GIZMAG (Nov. 2, 2010), http://www.gizmag.com/urbee-3d-printed-car/16795/.

[34] Clay Dillow, *UK Engineers Print and Fly the World's First Working 3-D Printed Aircraft*, POPULAR SCI. (July 28, 2011), http://www.popsci.com/technology/article/2011-07/uk-engineers-print-and-fly-worlds-first-working-3-d-printed-aircraft.

[35] David B. Kolesky et al., *3D Bioprinting of Vascularized, Heterogeneous Cell-Laden Tissue Constructs*, 26 ADVANCED MATERIALS 3124, 3124 (2014); Andy Coghlan, *3D Printer Makes Tiniest Human Liver Ever*, NEWSCIENTIST (Apr. 23, 2013), http://www.newscientist.com/article/dn23419-3d-printer-makes-tiniest-human-liver-ever.html#.U4eQePldXPg; Susan Young Rojahn, *Artificial Organs May Finally Get a Blood Supply*, MIT TECH. REV. (Mar. 6, 2014), http://www.technologyreview.com/news/525161/artificial-organs-may-finally-get-a-blood-supply/.

[36] Rhys Jones et al., *RepRap—The Replicating Rapid Prototyper*, 29 ROBOTICA 177, 177 (2011).

[37] *Id.* at 181–82.

[38] *Id.* at 190.

In 2009, a key patent covering the basics of fused filament fabrication expired,[39] opening doors for many small and medium enterprises to develop and sell their own 3D printers. The result was that "everything exploded,"[40] and now hundreds of small businesses build and sell low-cost, RepRap-derived 3D printers directly to consumers. Microbusinesses, like makexyz, of a single printer user are now operating in communities, and larger companies, such as Shapeways, Ponoko, and i.Materialise, are bringing 3D printing to the average consumer by offering 3D printing services online.[41]

Intriguingly, many of the early patents that cover basic 3D printing technology, including laser sintering, described below, have or will soon expire.[42] These expirations bring this technology into the public domain, allowing many small and medium enterprises to use this technology to develop their own printers and to develop this technology further.[43] Overall, these expirations will likely encourage significant open, low-cost innovation by increasing competition among manufacturers.

To allow the reader to understand the variety of 3D printing methods and materials available, this Article describes several key methods. For instance, laser-based additive manufacturing uses a laser to selectively melt, sinter, or clad metals, ceramics, or polymers.[44]

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[39] Apparatus and Method for Creating Three-Dimensional Objects, U.S. Patent No. 5,121,329 (filed Oct. 30, 1989).

[40] Christopher Mims, *3D Printing Will Explode in 2014, Thanks to the Expiration of Key Patents*, QUARTZ (July 21, 2013), http://qz.com/106483/3d-printing-will-explode-in-2014-thanks-to-the-expiration-of-key-patents.

[41] TJ McCue, *Custom Parts Made to Order with Ponoko*, FORBES (Jan. 31, 2012, 3:03 AM), http://www.forbes.com/sites/tjmccue/2012/01/31/custom-parts-made-to-order-with-ponoko/; Rachel Park, *3D Printing Service makexyz Growing Rapidly*, 3D PRINTING INDUSTRY (Apr. 8, 2013), http://3dprintingindustry.com/2013/04/08/3d-printing-service-makexyz-growing-rapidly/; Howard Smith, *i.Materialise or Shapeways?*, 3D PRINTING NEWS AND TRENDS (Mar. 11, 2013), http://3dprintingreviews.blogspot.com/2013/03/imaterialise-or-shapeways.html; Wohlers & Gornet, *supra* note 29, at 13.

[42] John Hornick & Dan Roland, *Many 3D Printing Patents Are Expiring Soon: Here's a Round Up & Overview of Them*, 3D PRINTING INDUSTRY (Dec. 29, 2013), http://3dprintingindustry.com/2013/12/29/many-3d-printing-patents-expiring-soon-heres-round-overview/ (listing expiring patents).

[43] *See, e.g.*, Mims, *supra* note 40.

[44] Edson Costa Santos et al., *Rapid Manufacturing of Metal Components by Laser Forming*, 46 INT'L J. MACHINE TOOLS & MANUFACTURE 1459, 1459. (2006).

Subsequent heat or pressure treatments accompany laser sintering to homogenize the material and remove any inherent porosity.[45] Laser cladding deposits material onto a substrate, either to add a coating or to build a new part.[46] Cladding can also repair defective or damaged parts. Parts produced through laser-based additive manufacturing typically have excellent dimensional control.[47] However, the use of hot lasers slows the build speed, and the requisite specialized gaseous atmospheres increase the price.[48]

Fused filament fabrication, also called fused deposition modeling, extrudes polymeric materials through a hot nozzle onto a stage in a laminar fashion.[49] This method can print in a wide range of thermoplastic polymers, including polycarbonate ("PC"), polylactic acid ("PLA"), acrylonitrile butadiene styrene ("ABS"), high density polyethylene ("HDPE"), recycled plastics, and even some polymer-based composites, though print resolution varies.[50] Fused filament fabricators make up for poorer resolution with phenomenally fast print speeds and low prices that have made them practical to utilize in offices, schools, and homes.[51]

Researchers have extended the process of welding to 3D printing.[52] 3D printing by welding is very similar to fused filament fabrication, but rather than extruding polymeric filament through a hot nozzle, metal filament is melted through an electric arc that forms between the welding gun and a metallic print substrate.[53] The use of a shield gas, such as argon with aluminum welding, is necessary during printing to prevent the formation of detrimental oxide layers. Gas metal arc welding,[54]

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[45] *Id.* at 1463.

[46] M.W. Khaing et al., *Direct Metal Laser Sintering for Rapid Tooling: Processing and Characterisation of EOS Parts*, 113 J. MATERIALS PROCESSING TECH. 269, 269 (2001).

[47] *Id.* at 270.

[48] *See* Santos, *supra* note 44, at 1462.

[49] D.T. Pham & R.S. Gault, *A Comparison of Rapid Prototyping Technologies*, 38 INT'L J. MACHINE TOOLS & MANUFACTURE 1257, 1269 (1998).

[50] *Id.* at 1270. In this context, if each layer is relatively thick, the resolution will be poor, much like bigger pixels on a computer screen result in poor 2D resolution.

[51] *Id.*

[52] Yu Ming Zhang et al., *Automated System for Welding-Based Rapid Prototyping*, 12 MECHATRONICS 37, 38 (2002).

[53] *Id.* at 37–38.

[54] Huihui Zhao et al., *A 3D Dynamic Analysis of Thermal Behavior During Single-Pass Multi-Layer Weld-Based Rapid Prototyping*, 211 J. MATERIALS PROCESSING TECH. 488, 488 (2011).

gas tungsten arc welding, electron beam melting,[55] electron beam freeform fabrication, and micro welding[56] are all commonly utilized, metal-based additive manufacturing techniques. The weld-based additive manufacturing techniques are typically inexpensive and produce metallic parts without porosity and with good interlayer adhesion.[57] Safety considerations require protection against exposure to the ultraviolet radiation emitted by the welding arc, electrical current of the arc, and high temperatures of the molten metal.

Stereolithography ("SLA"), the first commercialized form of 3D printing, utilizes ultraviolet light to cure portions of a photopolymer vat one layer at a time.[58] While 3D printing through stereolithography is generally a slow and expensive process, the parts produced by this method exhibit excellent resolution and dimensional control.[59] Famously, Align Technology uses stereolithography to make Invisalign clear dental braces.[60] Speeds of SLA technology, like Carbon3D's Continuous Liquid Interface Production ("CLIP") process, have recently improved by 25 to 100 times.[61]

Material jetting directly deposits droplets of material onto a printing substrate, similar to inkjet printing.[62] Alternatively, droplets of glues or other fixatives are deposited onto a bed of particles, and, in some cases, the glues or fixatives are removed through subsequent chemical or heat treatments.[63] Research has begun extending this technology to the printing of biological

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[55] Santos, *supra* note 44.

[56] Toshihide Horii et al., *Freeform Fabrication of Superalloy Objects by 3D Micro Welding*, 30 MATERIALS & DESIGN 1093, 1093 (2009); M. Katou et al., *Freeform Fabrication of Titanium Metal and Intermetallic Alloys by Three-Dimensional Micro Welding*, 28 MATERIALS & DESIGN 2093, 2094 (2007).

[57] Santos, *supra* note 44, at 1460.

[58] Pham & Gault, *supra* note 49, at 1259.

[59] *Id.* at 1263–64.

[60] Press Release, Align Tech., Inc., Align Tech. Is Awarded for Excellence in Med. Design & Mfg. (Mar. 12, 2002), *available at* http://files.shareholder.com/downloads/ALGN/3391551229x0x45196/fbfb5ca3-db23-4db1-a90e-804a548ea1d1/ALGN_News_2002_3_12_Financial_Releases.pdf.

[61] Brian Krassenstein, *Carbon3D Unveils Breakthrough CLIP 3D Printing Technology*, *25-100X Faster*, 3DPRINT.COM, (Mar. 16, 2015), http://3dprint.com/51566/carbon3d-clip-3d-printing/.

[62] Kaufui V. Wong & Aldo Hernandez, *A Review of Additive Manufacturing*, 2012 ISRN MECHANICAL ENGINEERING. 1, 5 (2012).

[63] *Id.*

tissue.[64] This method of 3D printing can be expensive and limited in regard to mechanical integrity, but it also provides exceptional resolution and dimensional control.

Shape deposition manufacturing is a hybrid form of 3D printing that applies additive and subtractive manufacturing techniques to produce high-quality parts.[65] This process is time consuming and expensive as both printing and milling processes are required, but it produces parts with excellent resolution. While still in the research phase, large corporations could likely implement this technology with success.

B. Biological Manufacturing: Synthetic Biology

The end goal of synthetic biology is to produce chemicals atom-by-atom. Rather than using generic one-size-fits-all medicines, one day it may be possible to go to the doctor for an ailment, harvest your body's own stem cells, and have medicines and therapies built specifically for you. Rather than using huge tracts of land to grow biomass for the production of biofuels, rewired molecules could be built in a lab to produce fuel more efficiently. It may be possible to engineer molecules to solve some of the toughest issues, such as cleaning up hazardous waste and cleaning inside active systems and pipes. This could all be made possible through the use of synthetic biology. Synthetic biology uses the building blocks of life at the sub-DNA level to redesign life as we know it, producing organisms with new abilities and functions.

Synthetic biology research has already led to some significant breakthroughs. For instance E. coli, the bacterium responsible for many unfortunate gastrointestinal issues, has been rewired by scientists to target and destroy colon infection and cancer.[66] Building microbials and chemicals from basic building blocks allows researchers to produce synthetic

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[64] Vladimir Mironov et al., *Organ Printing: Computer-Aided Jet-Based 3D Tissue Engineering*, 21 TRENDS BIOTECHNOLOGY 157, 157 (2003).

[65] Sreenathbabu Akula & K.P. Karunakaran, *Hybrid Adaptive Layer Manufacturing: An Intelligent Art of Direct Metal Rapid Tooling Process*, 22 ROBOTICS & COMPUTER-INTEGRATED MANUFACTURING 113, 113–14 (2006); Yong-Ak Song et al., *3D Welding and Milling: Part I–A Direct Approach for Freeform Fabrication of Metallic Prototypes*, 45 INT'L J. MACHINE TOOLS & MANUFACTURE 1057, 1057 (2005).

[66] Warren C. Ruder et al., *Synthetic Biology Moving into the Clinic*, 333 SCI. 1248, 1249–50 (2011).

antimalarial medicines in a cost-effective manner.[67] The efficient production of biofuels from biomass is yet another promising result of synthetic biology research.[68]

The ability to 3D print synthetic biology could make it even easier to develop synthetic organisms and to bring them to commercial production.[69] In synthetic biology, it can be very difficult to situate all of the nuts and cogs of life into the correct position with the requisite accuracy and resolution.[70] Using a new 3D printing technique known as microcontact printing could simplify this process.[71] Microcontact printing utilizes a polymeric stamp that is coated with the molecules of interest—including proteins, antibodies, and DNA.[72] This stamp is pressed against a clean substrate to apply a monolayer of molecules.[73] Researchers have already performed 3D printing arrays of protein and DNA molecules using this new method.[74] Utilizing the computer programs and databases related to synthetic biology that are currently under development,[75] it may not be long until researchers have the ability to design a molecule on a computer and directly 3D print it.

C. *Cloud Computing*

Another disruptive technology, cloud computing, is changing the landscape of computing at both the personal and commercial level.[76] The average person interfaces with programs that use cloud computing in some form or fashion on a daily basis. For instance, Google's e-mail service Gmail, Google documents,

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[67] Jay D. Keasling, *Synthetic Biology for Synthetic Chemistry*, 3 ACS CHEMICAL BIOLOGY 64, 70 (2008).

[68] Ahmad S. Khalil & James J. Collins, *Synthetic Biology: Applications Come of Age*, 11 NATURE REVIEWS GENETICS 367, 374 (2010).

[69] Priscilla E.M. Purnick & Ron Weiss, *The Second Wave of Synthetic Biology: From Modules to Systems*, 10 NATURE REVIEWS MOLECULAR CELL BIOLOGY 410, 410 (2009).

[70] *Id.* at 410–11.

[71] Sebastian A. Lange et al., *Microcontact Printing of DNA Molecules*, 76 ANALYTICAL CHEMISTRY 1641, 1641 (2004).

[72] *Id.*

[73] *Id.*

[74] *Id.*; J.P. Renault et al., *Fabricating Arrays of Single Protein Molecules on Glass Using Microcontact Printing*, 107 J. PHYSICAL CHEMISTRY B 703, 703 (2003).

[75] Purnick & Weiss, *supra* note 69, at 419.

[76] Greg Satell, *Why the Cloud Just Might Be the Most Disruptive Technology Ever*, FORBES (Jan. 5, 2014, 11:50 PM), http://www.forbes.com/sites/gregsatell/2014/01/05/why-the-cloud-just-might-be-the-most-disruptive-technology-ever.

Facebook, and Twitter all use cloud-based technology.[77] Cloud computing is experiencing a huge increase in research, development, and utilization in recent years as many entrepreneurs and small businesses utilize the services made available by cloud computing.[78]

Cloud computing is a centralized form of computing in which the average user employs the Internet to access programs, files, and services stored on servers at an external, fixed location.[79] It can turn computing and software into a pay-as-you-use utility.[80] It allows users to access information, programs, and computing power from any web-capable device in any location that has access to the Internet. For instance, a researcher on vacation can remotely access the expensive computational programs and computational power needed for research.[81]

Many entrepreneurs and small businesses have begun utilizing cloud computing as a means to reduce their start-up costs.[82] For their first three years, most businesses can save nearly thirty percent in IT-related expenditures by utilizing cloud-based services rather than installing their own server and information technology infrastructure.[83] During their first three years, businesses can also readily expand or contract their cloud services to meet their growing or shrinking business, reducing risk.[84] Cloud-based services also grant new businesses access to

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[77] Nicholas A. Ogunde & Jörn Mehnen, *Factors Affecting Cloud Technology Adoption: Potential User's Perspective*, *in* CLOUD MANUFACTURING: DISTRIBUTED COMPUTING TECHNOLOGIES FOR GLOBAL AND SUSTAINABLE MANUFACTURING 77, 78 (Weidong Li & Jörn Mehnen eds., 2013); Sean Marston et al., *Cloud Computing—The Business Perspective*, 51 DECISION SUPPORT SYSTEMS 176, 178 (2011).

[78] Rajkumar Buyya et al., *Cloud Computing and Emerging IT Platforms: Vision, Hype, and Reality for Delivering Computing as the 5th Utility*, 25 FUTURE GENERATION COMPUTER SYSTEMS 599, 599 (2009); Ogunde & Mehnen, *supra* note 77.

[79] Buyya, *supra* note 78; Ogunde & Mehnen, *supra* note 77, at 79.

[80] Buyya, *supra* note 78.

[81] *See* Marston, *supra* note 77; Ogunde & Mehnen, *supra* note 77, at 81.

[82] Joe McKendrick, *How Cloud Computing Is Fueling the Next Startup Boom*, FORBES (Nov. 1, 2011, 6:00 AM), http://www.forbes.com/sites/joemckendrick/2011/11/01/cloud-computing-is-fuel-for-the-next-entrepreneurial-boom/; *Silver Linings: Banks Big and Small Are Embracing Cloud Computing*, ECONOMIST, Jul. 20, 2013, *available at* http://www.economist.com/news/finance-and-economics/21582013-banks-big-and-small-are-embracing-cloud-computing-silver-linings?zid=291&ah=906e69ad01d2ee51960100b7fa502595.

[83] McKendrick, *supra* note 82.

[84] Cade Metz, *Why Some Startups Say the Cloud Is a Waste of Money*, WIRED (Aug. 15, 2013, 6:30 AM), http://www.wired.com/2013/08/memsql-and-amazon/.

supercomputers and other high-performance computing technologies. These factors help reduce barriers to entry and encourage business growth at a time that businesses are most vulnerable.

Cloud computing is significantly affecting manufacturing. The combination of concepts from cloud computing and manufacturing has led to a new concept known as cloud manufacturing. Cloud manufacturing treats the manufacturing cycle as a service or utility rendered to the customer rather than a production-based system.[85] Services include design of a part or a system, part production, experimentation within a system, and simulation and modeling, just to name a few.[86] Although this is a new concept, further development may also lead to drastically reduced costs for start-up manufacturing companies or any company that sells manufactured goods.

II. HOW NEW TECHNOLOGY LOWERS THE COSTS AND RISKS OF INNOVATION

The innovation[87] cycle can be described as involving the following stages: (1) basic research, (2) invention and prototyping, (3) product[88] development, (4) obtaining funding, and (5) marketing and distribution.[89] Of course, the innovation

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[85] Xun Xu, *From Cloud Computing to Cloud Manufacturing*, 28 ROBOTICS & COMPUTER-INTEGRATED MANUFACTURING 75, 79 (2012).

[86] Lin Zhang et al., *Cloud Manufacturing: A New Manufacturing Paradigm*, 8 ENTERPRISE INFO. SYSTEMS 167, 174 (2014).

[87] Much of the economic and business literature uses terms such as "technological advance" to refer to what the law literature calls "innovation"; it also uses the term "innovation" to refer to what the law literature calls "commercialization." *See* W. Rupert Maclaurin, *The Sequence from Invention to Innovation and its Relation to Economic Growth*, 67 Q.J. ECON. 97, 97 (1953).

[88] This Article uses "product" for convenience, but services are also included.

[89] Support for these stages can be found in numerous sources. *See, e.g.*, INDUS. RESEARCH INST., INC., RESEARCH IN INDUSTRY: ITS ORGANIZATION AND MANAGEMENT 4 (C.C. Furnas ed., 1948) (listing fundamental research, applied research, development, and production); Maclaurin, *supra* note 87, at 98 (listing the stages of technological advance as developing pure science, inventing, innovating, financing innovation, and accepting innovation); Atul Nerkar & Scott Shane, *Determinants of Invention Commercialization: An Empirical Examination of Academically Sourced Inventions*, 28 STRATEGIC MGMT. J. 1155, 1156 (2007) ("The introduction of a new product or service to the marketplace is 'a process that begins with an invention, proceeds with the development of the invention, and results in the introduction of a new product, process[,] or service to the marketplace.' " (citation omitted)); Sichelman, *supra* note 8, at 349–53.

cycle is not purely linear; there are many feedback loops among the stages.[90] Although there can be many additional stages or substages, this simplified model is sufficient to analyze recent and emerging technologies' effects on the costs and risks of innovation.[91]

After giving an overview of each innovation stage, this Part demonstrates how technology has and will continue to dramatically lower the costs of each stage. To give force to this assertion, and given the authors' expertise, this Part provides robust discussion of the cost savings from 3D printing. This Part also provides examples of other cost-saving technologies, although space constraints require that this Part does not fully elaborate on each example.

A. Basic Research

Basic research includes academic and private research, and it produces knowledge that can be applied in many innovations. Familiar examples include Albert Einstein's theory of relativity and the mass-energy equivalence—$E=mc^2$—or Michael Faraday's contributions to electromagnetism. Although basic research is an important component of innovation, it rarely leads directly to immediate technological change.[92] Rather, it adds to the cumulative storehouse of fundamental knowledge necessary to employ and advance the remaining stages of innovation.[93]

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[90] Stephen J. Kline, *Innovation Is Not a Linear Process*, 28 RES. MGMT. 36, 36–41 (1985) (discussing feedback links that form a linked-chain model for innovation).

[91] Margherita Balconi, Stefano Brusoni & Luigi Orsenigo, *In Defence of the Linear Model: An Essay*, 39 RES. POL'Y 1, 9–10 (2010) (arguing that the linear model, properly understood, is a useful analytical tool).

[92] Maclaurin, *supra* note 87, at 99 ("Pure science rarely leads *directly* to a patentable invention or to immediate technological change."); Edwin Mansfield, *Academic Research and Industrial Innovation*, 20 RES. POL'Y 1, 11 (1991) (finding that only about ten percent of the new products and processes studied "could not have been developed (without substantial delay) in the absence of recent academic research").

[93] Kline, *supra* note 90, at 44; Mansfield, *supra* note 92 (finding, with conservative estimates, the social rate of return from academic research from 1975 to 1978 to be twenty-eight percent).

1. 3D Printing

The rise of 3D printing has the ability to reduce significantly the costs of basic research by (1) reducing the costs of scientific hardware by a factor of 10 to 100 and (2) reducing the costs of training highly qualified personnel.

Innovators in all industries have limited access to the best scientific tools to do basic research largely due to the inflated prices of proprietary scientific equipment for experimental research.[94] This slows the rate of scientific development in every field. Historically, the scientific community had to choose one of two suboptimal paths to participate in state-of-the-art experimental research: (1) purchase high-cost proprietary tools[95] or (2) develop equipment largely from scratch in scientists' own labs, which often involves enormous time and effort. The high cost of modern scientific tools thus not only excludes many potential scientists from participating in the scientific endeavor, but also slows the progress in all laboratories.

With 3D printing and the sharing of free and open-source digital scientific equipment designs, there is now a significantly lower cost option.[96] The highly sophisticated and customized scientific equipment is being developed as free and open-source hardware[97] ("FOSH") similar to free and open source software[98] ("FOSS"). FOSH provides the code for hardware, including the bill of materials, schematics, instructions, computer-aided drafting ("CAD") designs, and other information needed to

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[94] JOSHUA M. PEARCE, OPEN-SOURCE LAB: HOW TO BUILD YOUR OWN HARDWARE AND REDUCE RESEARCH COSTS, at ix (2014).

[95] These tools are expensive in a large part because of the large overhead associated with making low-volume products and the lack of competition in the scientific hardware market, as compared to more traditional large-volume consumer markets.

[96] Joshua M. Pearce, *Building Research Equipment with Free, Open-Source Hardware*, 337 SCI. 1303, 1303–04 (2012).

[97] CHRIS ANDERSON, MAKERS: THE NEW INDUSTRIAL REVOLUTION 107–10 (2012); Daniel K. Fisher & Peter J. Gould, *Open-Source Hardware Is a Low-Cost Alternative for Scientific Instrumentation and Research*, 1 MOD. INSTRUMENTATION 8, 8–9 (2012).

[98] PEARCE, *supra* note 94, at 1 ("*FOSS* is a computer software that is available in source code (open source) form and that can be used, studied, copied, modified, and redistributed without restriction, or with restrictions that only ensure that further recipients have the same rights under which it was obtained (free or libre)."). For more on FOSS, see Greg R. Vetter, *Commercial Free and Open Source Software: Knowledge Production, Hybrid Appropriability, and Patents*, 77 FORDHAM L. REV. 2087, 2094–108 (2009).

recreate a physical artifact. Similar to FOSS,[99] FOSH leads to improved product innovation in a wide range of fields.[100] Hundreds of scientific tools have already been developed to allow free access to plans, and this trend is assisting scientific development in every field that it touches.[101]

For example, one can 3D print a much-used piece of equipment in biology and medical research labs—the laboratory pipette—for a few dollars, replacing a commercial pipette that costs over $100.[102] As another example, consider the test-tube rack. Because 3D printing complex objects is not difficult for 3D printers, it is just as easy to 3D print an inexpensive test tube rack as it is to make an $850 magnetic test tube rack.[103] The designs have already been open-sourced for a 3D-printable ninety-six well plate strip tube magnet rack that holds six-dollar magnets,[104] among several other magnetic rack designs.

To understand how expensive scientific equipment normally is, consider that it is possible to justify economically the purchase of a $500 open-source RepRap3D printer[105] by 3D printing a single standard commercial magnetic rack. The 3D printer, which can pay for itself by making one piece of lab equipment, can then make a long list of progressively more sophisticated and costly tools. A few examples include: Environmental scientists can print and build a hand-held, portable, open-source

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[99] There is a large body of literature dedicated to showing the superiority of FOSS development. *See, e.g.*, FADI P. DEEK & JAMES A.M. MCHUGH, OPEN SOURCE: TECHNOLOGY AND POLICY 2–3 (2008); CHRIS DIBONA ET AL., *Introduction* to OPEN SOURCES: VOICES FROM THE OPEN SOURCE REVOLUTION 7 (Chris DiBona et al. eds., 1999); JOHAN SÖDERBERG, HACKING CAPITALISM: THE FREE AND OPEN SOURCE SOFTWARE MOVEMENT 137 (2012); Karim R. Lakhani & Eric von Hippel, *How Open Source Software Works: "Free" User-to-User Assistance*, 32 RES. POL'Y 923, 923 (2003); Eric Raymond, *The Cathedral and the Bazaar*, 12 KNOWLEDGE TECH. & POL'Y 23, 23 (1999).

[100] There are dozens of examples in different fields. *See, e.g.*, PEARCE,, *supra* note 94, at 14; Fisher & Gould, *supra* note 97, at 9; Christoph Hienerth, Eric von Hippel & Morten Berg Jensen, *User Community vs. Producer Innovation Development Efficiency: A First Empirical Study*, 43 RES. POL'Y 190, 199 (2014).

[101] PEARCE, *supra* note 94, at vii–viii.

[102] Lewisite, *Laboratory Pipette*, THINGIVERSE (Oct. 1, 2013), http://www.thingiverse.com/thing:159052.

[103] Magnetic test tube racks are simply racks with magnets added and are used for molecular and cell-separation applications.

[104] Acadey, *96 Well Plate/0.2 mL Strip Tube Magnet Rack*, THINGIVERSE (Apr. 24, 2013), http://www.thingiverse.com/thing:79430.

[105] B.T. Wittbrodt et al., *Life-Cycle Economic Analysis of Distributed Manufacturing with Open-Source 3-D Printers*, 23 MECHATRONICS 713, 719 (2013).

colorimeter to do COD measurements[106] for under $50, replacing similar hand-held tools that cost over $2,000;[107] civil engineers can spend less than $80 to make a tool for nephelometry, replacing an approximately $1,200 tool;[108] physicists can make automated devices for doing opto-electronic experiments, such as a filter wheel, for $50, replacing inferior commercial tools that cost $2,500;[109] biologists can print a syringe pump and automate it for under $100, replacing traditional syringe pumps that range from $260 to over $5,000.[110]

Because researchers can replicate each of the designs for little more than the cost of materials, the economic value for the scientific community is staggering. Within a month of the release of the open-source syringe pump designs, the scientific community saved over $1,000,000 in high-end syringe pump purchases.[111] This FOSH investment provides returns for funders ranging from hundreds to thousands of percent after only a few months.[112] Moreover, scientists are pushing ever more complex tools, such as the open mesoscopy,[113] and are using 3D

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[106] A colorimeter measures the intensity of color. In environmental chemistry, the chemical oxygen demand (COD) test is an indirect measure of the density of organic compounds in water. Normally, such scientists are looking for organic pollutants found in surface water such as lakes and rivers, or they are civil engineers treating wastewater and thus using COD as a method to quantify water quality.

[107] Gerald C. Anzalone et al., *Open-Source Colorimeter*, 13 SENSORS 5338, 5342 (2013), *available at* http://www.mdpi.com/1424-8220/13/4/5338/htm.

[108] Bas Wijnen, G.C. Anzalone & Joshua M. Pearce, *Open-Source Mobile Water Quality Testing Platform*, 4 J. WATER SANITATION & HYGIENE FOR DEV. 532, 534 (2014). Nephelometry refers to the measurement of the size and concentration of particles in a liquid by analysis of light scattered by the liquid.

[109] Joshua M. Pearce,, *supra* note 96, at 1304. A filter wheel is a device used to automate the positioning of filters in the path of a light ray for scientific experiments, such as testing solar photovoltaic quantum efficiency.

[110] Bas Wijnen et al., *Open-Source Syringe Pump Library*, 9 PLOS ONE 1, 6 (2014), *available at* http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0107216. A syringe pump is a small infusion pump used to precisely administer small amounts of fluid—with or without medication—to a patient or for use in chemical and biomedical research.

[111] Joshua M. Pearce, *Quantifying the Value of Open Source Hardware Development*, 6 MOD. ECON. 1, 4 (2015).

[112] Joshua M. Pearce, *Return on Investment for Open Source Hardware Development*, SCI. & PUB. POL'Y 1, 4 (2015), DOI :10.1093/scipol/scv034.

[113] Emilio Gualda et al., *Going "Open" with Mesoscopy: A New Dimension on Multi-View Imaging*, 251 PROTOPLASMA 363, 365–68 (2014). In this case, high-resolution 3D mesoscopic images of biological research in the 1–10mm size region.

printing to print animal and human tissue.[114] Now that open-source 3D bioprinting is possible with a range of technologies,[115] these types of fully open-source, 3D printing-enabled technologies are emergent.

In addition, chemists have begun to experiment with making 3D printable reactionware,[116] liquid handling,[117] and 3D printable microfluidics[118] that have the potential to drive down the cost of complicated chemical synthesis and lab-on-a-chip technology. Such technology will allow for further experiments in a wide range of fields and expand the range of 3D printing materials in a systematic way.[119] Even top-end equipment is becoming open-source, such as an $800 microscope that replaces an $80,000 conventional equivalent.[120] As the number of materials used in these low-cost 3D printers continues to expand, the number of applications will expand as well, thus continuing to drive down the cost of scientific hardware.

Even more important than the equipment costs for basic research are the highly qualified personnel who do the innovating. Advanced training in Science, Technology, Engineering, and Mathematics ("STEM") is an integral part of the research and development needed to foster discovery, innovation, productivity, and to keep the United States competitive internationally.[121] STEM education costs more than most traditional classroom instruction in large part because of the high costs of scientific hardware and lab supplies discussed

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[114] Lingling Zhao et al., *The Integration of 3-D Cell Printing and Mesoscopic Fluorescence Molecular Tomography of Vascular Constructs Within Thick Hydrogel Scaffolds*, 33 BIOMATERIALS 5325, 5326, 5332 n.23 (2012).

[115] Patrik, *DIY BioPrinter*, INSTRUCTABLES, http://www.instructables.com/id/DIY-BioPrinter/ (last visited Apr. 1, 2016).

[116] Mark D. Symes et al., *Integrated 3D-Printed Reactionware for Chemical Synthesis and Analysis*, 4 NAT. CHEMISTRY 349, 349 (2012).

[117] Philip J. Kitson et al., *Combining 3D Printing and Liquid Handling To Produce User-Friendly Reactionware for Chemical Synthesis and Purification*, 4 CHEMICAL SCI. 3099, 3099 (2013).

[118] Philip J. Kitson et al., *Configurable 3D-Printed Millifluidic and Microfluidic 'Lab on a Chip' Reactionware Devices*, 12 LAB ON CHIP 3267, 3267 (2012).

[119] Joshua M. Pearce, *A Novel Approach to Obviousness: An Algorithm for Identifying Prior Art Concerning 3-D Printing Materials*, 42 WORLD PAT. INFO. 13, 13–14 (2015).

[120] *Open-Source Through the Lens of a Microscope*, U. CAMBRIDGE (Nov. 7, 2013), http://www.eng.cam.ac.uk/news/open-source-through-lens-microscope.

[121] Anthony P. Carnevale et al., *STEM*, GEO. U. CENTER ON EDUC. & WORKFORCE (Oct. 20, 2011), http://cew.georgetown.edu/STEM/.

above. The high costs often limit access to exciting and engaging labs in both K-12 and university education, weakening recruitment of future STEM talent.[122] The upshot of limited access to STEM education is about four million unfilled jobs in the United States due to inadequate numbers of college graduates in STEM-related disciplines.[123]

FOSH concepts can emphatically reduce costs for K-12 STEM education, resulting in tens of millions of dollars saved.[124] This would increase access to STEM training and increase recruitment, leading to a virtuous cycle for future innovation.[125]

2. Other Technologies

This Subsection briefly mentions other technologies that do, or likely one day will, reduce the costs of basic research. Most obviously, the Internet and the reduced costs of computing power and memory fundamentally affect basic research costs by allowing researchers to communicate, share, and research in ways previously unimaginable.

[122] Jacob Gutnicki, *The Evolution of Teaching Science*, LISA NIELSEN: THE INNOVATIVE EDUCATOR (Feb. 28, 2010), http://theinnovativeeducator.blogspot.com/2010/02/evolution-of-teaching-science.html.

[123] *Increasing the Achievement and Presence of Under-Represented Minorities in STEM Fields*, NAT'L MATH & SCI. INITIATIVE, http://nms.org/Portals/0/Docs/whitePaper/NACME%20white%20paper.pdf (last visited Apr. 1, 2016).

[124] *See* Chenlong Zhang et al., *Open-Source 3D-Printable Optics Equipment*, 8 PLOS ONE 1 (2013) (detailing open-source optics lab equipment, including optical rails, optical lens holders, adjustable lens holders, ray optical kits, and viewing screens).

[125] *See* Rachel Goldman et al., *Using Educational Robotics To Engage Inner-City Students with Technology*, http://er.jsc.nasa.gov/seh/Robot_PDF_Files/robot_edu_inner_city.pdf (last visited Apr. 1, 2016); John L. Irwin et al., *The RepRap 3-D Printer Revolution in STEM Education*, 360° ENGINEERING EDUC., http://www.asee.org/public/conferences/32/papers/8696/view (last visited Apr. 1, 2016); Jakob Kentzer et al., *An Open Source Hardware-Based Mechatronics Project: The Replicating Rapid 3-D Printer*, RESEARCHGATE (Jan. 2011), http://www.researchgate.net/publication/252013651_An_open_source_hardware-based_mechatronics_project_The_replicating_rapid_3-D_printer.

Cloud computing can provide cheaper and better tools for basic scientific research.[126] Among other things, cloud computing allows individuals to access large-scale computational resources without the need to purchase a mainframe computer.[127] By paying for these services only on an as-needed basis, researchers gain access and save money.

In addition, FOSS has obvious abilities to lower costs to researchers because the software is free. Myriad specialized programs have proliferated due to researcher use across a variety of disciplines.[128] More broadly than direct application to basic research, but no less important, FOSS components like Linux, MySQL, and more, provide an inexpensive means for individuals, researchers, groups, and even countries to use free, sophisticated technology and even develop an entire technological infrastructure.[129]

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[126] *Understanding Cloud Computing for Research and Teaching*, ESCIENCE INST., http://escience.washington.edu/get-help-now/understanding-cloud-computing-research-and-teaching (last visited Nov. 7, 2015) (describing the benefits of cloud computing for research).

[127] *See, e.g.*, *Cloud Computing Brings Cost of Protein Research Down to Earth*, SCIENCEDAILY (Apr. 13, 2009), http://www.sciencedaily.com/releases/2009/04/090410100940.htm; Ben Langmead et al., *Cloud-Scale RNA-Sequencing Differential Expression Analysis with Myrna*, 11 GENOME BIOLOGY 1, 1 (2011), http://genomebiology.com/content/pdf/gb-2010-11-8-r83.pdf (describing a cloud-computing-based software that increases the speed at which scientists can analyze RNA sequencing data).

[128] *See, e.g.*, Scott L. Delp et al., *OpenSim: Open-Source Software To Create and Analyze Dynamic Simulations of Movement*, 54 IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING 1940, 1940 (2007) (describing an open source software tool to study human movement); Paolo Giannozzi et al., *Quantum Espresso: A Modular and Open-Source Software Project for Quantum Simulations of Materials*, 21 J. PHYSICS CONDENSED MATTER 1, 2 (2009) (describing an integrated suite of computer codes for electronic-structure calculations and materials modeling).

[129] SAMIR CHOPRA & SCOTT D. DEXTER, DECODING LIBERATION: THE PROMISE OF FREE AND OPEN SOURCE SOFTWARE, at xv (2007) ("FOSS provides a social good that proprietary software cannot; for example, FOSS may be the only viable source of software in developing nations, . . . [through which they can] draw on their wealth of programming talent to provide the technological infrastructure for their rapidly expanding economies."); Christof Ebert, *Open Source Drives Innovation*, 24 IEEE SOFTWARE 105, 105 (2007) ("The software world we have is unimaginable without open source operating systems, databases, application servers, Web servers, frameworks, and tools. Brands such as Linux, MySQL, Apache, and Eclipse, together with their underlying software, have dramatically shaped product and service development.").

The biotechnology sector includes its own open source movement that can provide researchers with cheap access to basic research tools.[130] Specialized fields such as synthetic biology are likewise attempting to foster open innovation models.[131] Even apart from open-source models, the costs of some basic biotechnology functions have decreased dramatically. Perhaps the most striking example is the decreased cost of genetic sequencing, which has decreased at a rate that far outpaced Moore's law. While the cost of sequencing 1,000,000 DNA base pairs was about $1,000 in 2004, by 2011 the cost had fallen to an amazing 10¢.[132] Knowing the DNA sequences of an organism is a basic research step that must occur before various follow-on research can occur.[133]

B. *Invention and Prototyping*

The invention and prototyping stage starts with the recognition of a problem, continues with the mental conception of a solution to that problem,[134] and ends roughly with the creation of detailed design drawings and an initial working prototype.[135]

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[130] *See generally* JANET HOPE, BIOBAZAAR: THE OPEN SOURCE REVOLUTION AND BIOTECHNOLOGY (2008) (describing the fledgling open source biotechnology movement and exploring whether it can expand to a robust phenomenon). *See also* Robin Feldman, *The Open Source Biotechnology Movement: Is It Patent Misuse?*, 6 MINN. J.L. SCI. & TECH. 117, 118 (2004) ("Building on the software notion of 'copyleft,' some open source biotechnology projects use the power of the patent system to ensure that the core technology of the project and any innovations remain openly available.").

[131] Sapna Kumar & Arti Rai, *Synthetic Biology: The Intellectual Property Puzzle*, 85 TEX. L. REV. 1745, 1763 (2007) ("The idea of a synthetic biology commons draws inspiration, in part, from the prominence of the open-source software model as an alternative to proprietary software.").

[132] Kris Wetterstrand, *DNA Sequencing Costs: Data from the NHGRI Genome Sequencing Program (GSP)*, GENOME, http://www.genome.gov/sequencingcosts/ (last updated Jan. 15, 2016).

[133] *See* KEVIN DAVIES, THE $1,000 GENOME: THE REVOLUTION IN DNA SEQUENCING AND THE NEW ERA OF PERSONALIZED MEDICINE 12–13 (2015) (describing the potential research and personalized medicine made possible by cheap DNA sequencing); *A Brief Guide to Genomics*, GENOME, http://www.genome.gov/18016863 (last updated Aug. 27, 2015) ("Researchers can use DNA sequencing to search for genetic variations and/or mutations that may play a role in the development or progression of a disease.").

[134] Sichelman, *supra* note 8, at 348–50.

[135] Kline, *supra* note 90, at 37 (discussing the creation of design drawings and prototypes); Maclaurin, *supra* note 87, at 102 ("[I]nvention . . . discloses an operational method of creating something new." (emphasis omitted)).

1. 3D Printing

3D printing enables design ideas developed in CAD to be easily fabricated on the same day.[136] The printed 3D prototype can then be tested, studied, and refined quickly.[137] Then, developers either can manufacture the finalized design by some other process or fabricate it by a 3D printer for use.[138] In contrast, traditional methods of making prototypes—for example, modelmaking by hand and machining—are both time-consuming and expensive.[139]

The expiration of key patents and the rise of open-source 3D printers have lowered the cost of rapid prototyping to within the reach of all professional engineers and scientists and a large swath of the public.[140] Invention and prototyping has thus been redemocratized. Rapid prototyping not only speeds up the innovation cycle, but also radically reduces its costs, enabling even casual inventors to participate in the innovation process.[141]

For example, consider invention and prototyping in heat exchanger design. Traditionally, heat exchangers are made from metal, which transfers heat well.[142] Polymers—for example, garbage bags—with relatively poor thermal conductivity are rarely considered as a material for heat exchangers. However, if

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[136] CHEE KAI CHUA ET AL., RAPID PROTOTYPING: PRINCIPLES AND APPLICATIONS 13 (3d ed. 2010).

[137] *See* ANDREAS GEBHARDT, RAPID PROTOTYPING 30 (2003); *see also* CHUA, *supra* note 136, at 4–6.

[138] CHUA, *supra* note 136, at 8.

[139] *Id.* at 14.

[140] *See, e.g.*, Sahiti Uppada, *Expiry of Patents in 3D Printing Market To Decrease Product Costs and Increase Consumer Orientation*, 3D PRINTING (Sept. 24, 2015), http://3dprinting.com/news/expiry-of-patents-in-3d-printing-market-to-decrease-product-costs-and-increase-consumer-orientation/ ("When the patent containing Fluid Deposition Modeling (FDM), a rather primitive technology, had expired, it resulted in an immediate significant drop of prices from $1000 to approximately as low as $300–$400."); Pieter Van Lancker, *The Influence of IP on the 3D Printing Evolution*, CREAX (Aug. 12, 2015), https://www.creax.com/en/our-work/the-3d-printing-evolution-insights-on-the-influence-of-ip-on-technology-dev.

[141] CHUA, *supra* note 136, at 14–16.

[142] David C. Denkenberger et al., *Expanded Microchannel Heat Exchanger: Design, Fabrication, and Preliminary Experimental Test*, 226 PROC. INSTITUTION MECHANICAL ENGINEERS PART A: J. POWER & ENERGY 532, 532 (2012).

polymer walls are made thin, the thermal resistance is negligible, and the use of polymers to make an ultra-low-cost heat exchanger is theoretically possible.[143]

Without low-cost 3D printing, a polymer heat exchanger might have remained the stuff of theory or well-funded labs. Using a new form of 3D printing, however, scientists recently proved the plastic heat exchanger concept.[144] The original prototype for this exchanger cost $3,000. To reduce costs, the team invented an open-source, polymer laser welding system from customized 3D printed parts.[145] The open-source laser welder was far less costly than the custom commercial systems that manufactured the original prototype heat exchanger.[146]

In this single anecdote, 3D printing technology greatly facilitated two core inventions: first, a low-cost laser welder and second, a polymer-based heat exchanger. Moreover, the laser system can help produce numerous follow-on inventions. The system uses as 3D printing feedstock twenty-eight-micron thick black low density polyethylene ("LDPE") sheets—also known as garbage bags—and can output inexpensive, novel heat exchangers for a wide range of applications—from solar water pasteurizers[147] to heat recovery ventilators in cars and trucks.[148] This example is but one of thousands in the open source appropriate technology space.[149]

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[143] Microchannel Expanded Heat Exchanger, U.S. Patent No. 20120291991 A1 (filed Dec. 2, 2010).

[144] Denkenberger, *supra* note 142.

[145] PEARCE, *supra* note 94, at 189–90.

[146] The savings on the capital equipment, however, are trivial compared to the cost savings in making new heat exchanger designs. Users save about $2,950 every afternoon that they run the system to make a new design. These savings, however, relate more to the product development cycle. *See* discussion *infra* Part II.C.

[147] David Denkenberger & Joshua M. Pearce, *Compound Parabolic Concentrators for Solar Water Heat Pasteurization: Numerical Simulation*, 2006 INT'L CONF. SOLAR COOKING & FOOD PROCESSING 108.

[148] D. Denkenberger et al., *Towards Low-Cost Microchannel Heat Exchangers: Vehicle Heat Recovery Ventilator Prototype*, 2014 10TH INT'L CONF. ON HEAT TRANSFER FLUID MECHANICS & THERMODYNAMICS 2044, 2044.

[149] Joshua M. Pearce, *The Case for Open Source Appropriate Technology*, 14 ENV'T DEV. & SUSTAINABILITY 425, 425 (2012).

It bears emphasizing that low-cost, open-source 3D printing drives innovation not only among professional engineers and scientists, but also among the public, made up of an army of hobbyists, prosumers,[150] "makers,"[151] do-it-yourself-ers, backyard tinkerers, and even children. A new, vast collection of free and open-source CAD programs enables everyone with an interest in playing with 3D CAD to make new designs and then to 3D print the physical object, bringing their inventions to life. In addition, inventors often freely share their designs with creative commons or open source licenses, many of whom have a "ShareAlike" rider, which demands that those who build on the concept reshare their work with the community under the same license.[152] To get a feel for the momentum, consider that Thingiverse,[153] one of dozens of free 3D printable design web site repositories, currently has over 940,000 free designs, and an exponential increase in the rate of available, free 3D printable designs has already been documented.[154]

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[150] Prosumer is a portmanteau of producer and consumer; the idea being that consumers produce many of their own goods. ALVIN TOFFLER, THE THIRD WAVE 266 (1991).

[151] Stated most simply, a "maker" is one who makes things. In contemporary global society, a maker culture—or subculture—is evolving that represents a technology-focused extension of the do-it-yourself ("DIY") culture. Maker Media, who publishes Make Magazine—a publication largely of DIY projects for and about makers—claims, "Whether as hobbyists or professionals, [m]akers are creative, resourceful[,] and curious, developing projects that demonstrate how they can interact with the world around them. The launch of Make: magazine in 2005, followed by Maker Faire in 2006, jumpstarted a worldwide Maker Movement, which is transforming innovation, culture[,] and education." *Leading the Maker Movement*, MAKERMEDIA, http://makermedia.com/ (last visited Apr. 2, 2016). As would be expected, makers are heavily involved with 3D printing—most notably making up the majority of the developmental work on the RepRap project. *See Welcome to RepRap.org*, REPRAP, http://reprap.org/wiki/RepRap (last modified Jan. 20, 2016) (providing a platform where individuals working as hobbyists have contributed the large majority of innovations and variations).

[152] *See, e.g.*, *Creative Commons License Deed*, CREATIVE COMMONS, https://creativecommons.org/licenses/by-sa/3.0/us/ (last visited Apr. 2, 2016).

[153] MAKERBOTTHINGIVERSE, http://www.thingiverse.com/ (last visited Apr. 2, 2016).

[154] Wittbrodt, *supra* note 105.

2. Other Technologies

Other technologies also reduce the costs of invention and prototyping, especially for digital-based technology start-ups.[155] Easy-to-learn programming frameworks like Ruby on Rails and a digital commons of small bits of programming code foster the basic building blocks for all sorts of digital-based innovation. Remote independent developers accessible through on-demand Internet interfaces can create a prototype application ("app"), often called beta-tests.[156] Moreover, crowdsourcing platforms have emerged that assist in app creation, among other areas.[157] Using these resources, developers can create simple versions of apps and websites in a matter of days.[158]

More broadly, innovations such as crowdsourcing and on-demand services have provided cost-effective means for performing all sorts of tasks, including designing prototypes. For example, Quirky is an innovative company that accepts product ideas from the public and develops the most promising ones into prototypes and eventually finished products.[159] The company sees itself as "a modern invention machine."[160]

As the costs of DNA sequencing and synthesis continue to drop, lower costs will help produce a stream of biochemical inventions. In turn, this will call for mature synthetic biology and chemistry processes so that companies can construct their

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[155] *See, e.g.*, John F. Coyle & Joseph M. Green, *Contractual Innovation in Venture Capital*, 66 HASTINGS L.J. 133, 155 (2014) ("Over the past decade, the costs of launching a new technology start-up have fallen precipitously."); Mary Hurd, *What Does It Cost To Develop an App?*, FUELED (Sept. 29, 2015), http://fueled.com/blog/how-much-does-it-cost-to-develop-an-app/ (estimating that the average app costs about $120,000 to $150,000 to develop and noting that a proof-of-concept app can be created even more cheaply).

[156] *See, e.g.*, *The Workforce in the Cloud*, ECONOMIST (June 1, 2013), http://www.economist.com/news/business/21578658-talent-exchanges-web-are-starting-transform-world-work-workforce ("The top two skills hired on oDesk[, an on-demand service provider,] last year were in web programming and mobile apps.").

[157] *See, e.g.*, *App Development & Digital Innovation with Crowdsourcing*, APPIRIO, http://appirio.com/services/crowdsourcing/ (last visited Apr. 2, 2016).

[158] *Testing, Testing*, ECONOMIST (Jan. 18, 2014), http://www.economist.com/news/special-report/21593581-launching-startup-has-become-fairly-easy-what-follows-back-breaking ("A quick prototype can be put together in a matter of days . . . .").

[159] Adam Ludwig, *Don't Call It Crowdsourcing: Quirky CEO Ben Kaufman Brings Invention to the Masses*, FORBES (Apr. 23, 2012, 12:53 PM), http://www.forbes.com/sites/techonomy/2012/04/23/dont-call-it-crowdsourcing-quirky-ceo-ben-kaufman-brings-invention-to-the-masses/.

[160] Steve Lohr, *The Invention Mob*, N.Y. TIMES, Feb. 15, 2015, at BU1.

desired molecules quickly and cheaply.[161] Beyond the construction of individual molecules, one goal of the synthetic biology movement is to build biological systems from modules, which would facilitate the creation of prototypes and finished products.[162]

While nascent, these chemical and biological platforms are growing. So-called "biohackers" meet around the world in "hackerspaces" where even laypeople can build simple biological machines.[163] Some powerful tools of biology and chemistry are available even to undergraduate students, such as the team from Cambridge University that created different-colored versions of E. coli bacteria by inserting and modifying genes from other organisms.[164] As one Harvard Medical School professor stated, "[B]iological carbon is the silicon of this century,"[165] meaning that biological computers should take center stage in this century.

Separate but related to synthetic biology, molecular modeling can help reduce the costs of developing pharmaceutical drugs.[166] Molecular modeling software mimics and predicts how molecules will act, thus reducing the need for live experiments.[167]

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[161] *See, e.g.*, Drew Endy, *Foundations for Engineering Biology*, 438 NATURE 449, 449 (2005) (noting the need for technologies that enable routine engineering of biology).

[162] *See id.*; Katherine Xue, *Synthetic Biology's New Menagerie*, HARV. MAG., Sept.–Oct. 2014, at 42, 42–43.

[163] *LA Biohackers*, BIOHACKERS.LA, http://www.biohackers.la/ (last visited Apr. 2, 2016) (describing a biohackerspace in Los Angeles); *London Biohackspace*, BIOHACKSPACE.ORG, http://biohackspace.org/ (last visited Apr. 2, 2016) (describing a biohackerspace in London); *see also* Gaymon Bennett et al., *From Synthetic Biology to Biohacking: Are We Prepared?*, 27 NATURE BIOTECHNOLOGY 1109, 1109–11 (2009) (describing biohacking and raising questions about risks therefrom); *Biohackers of the World, Unite*, ECONOMIST (Sept. 6, 2014), http://www.economist.com/news/technology-quarterly/21615064-following-example-maker-communities-worldwide-hobbyists-keen-biology-have (describing the biohacker movement).

[164] Xue, *supra* note 162, at 42.

[165] *Id.*

[166] B. Thomas Watson, Note, *Carbons into Bytes: Patented Chemical Compound Protection in the Virtual World*, 12 DUKE L. & TECH. REV. 25, 26–27 (2014) (explaining that computer-aided de novo drug design can help identify lead compounds for future drugs); Kim-Mai Cutler, *TeselaGen Is Building a Platform for Rapid Prototyping in Synthetic Biology*, TECHCRUNCH (Mar. 10, 2014), http://techcrunch.com/2014/03/10/teselagen-is-building-a-platform-for-rapid-prototyping-in-synthetic-biology.

[167] AHINDRA NAG & BAISHAKHI DEY, COMPUTER-AIDED DRUG DESIGN AND DELIVERY SYSTEMS 9 (2011).

Although molecular modeling has not yet made large impacts on pharmaceutical or chemical inventions, commentators believe that increased computing power will increase its impact.[168]

C. Product Development

Generally speaking, the product development stage turns an initial prototype into a market-ready product.[169] This stage can be very complex and involve many steps, including testing the prototype—both in a physical and marketing standpoint—and continuously refining it based upon insights gleaned from testing.[170] In many cases, an ideal product development process would continually refine the prototype using knowledge gained from technical and market studies.[171] In such an environment, it is important to have quick and inexpensive incorporation of the refinement process.[172]

1. 3D Printing

If 3D printing brings value to the creation of the initial prototype, the technology multiplies its value exponentially when the prototype is updated and adjusted based on user feedback, technical assessment, and the like.[173] Rarely is a product design perfect the first time; it must go through dozens or even hundreds of iterations before going to market.[174]

Whereas traditional manufacturing techniques, such as casting, forming, joining, machining, and molding, might be slow and expensive, digital designs can be quickly adjusted in a CAD environment, shared electronically to a geographically dispersed design team, and then rendered into physical objects anywhere there is a 3D printer. This reduces design costs, transportation

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[168] Watson, *supra* note 166, at 27.

[169] Maclaurin, *supra* note 87, at 105.

[170] Kline, *supra* note 90, at 37–38 (discussing product development and feedback links).

[171] *See* Stephen J. Kline & Nathan Rosenberg, *An Overview of Innovation*, *in* THE POSITIVE SUM STRATEGY: HARNESSING TECHNOLOGY FOR ECONOMIC GROWTH 275, 289–91 (Ralph Landau & Nathan Rosenberg eds., 1986).

[172] *Id.* at 296 ("[S]peed of turnaround is a critical factor in the effectiveness of innovation.").

[173] S. Vinodh et al., *Agility Through Rapid Prototyping Technology in a Manufacturing Environment Using a 3D Printer*, 20 J. MANUFACTURING TECH. MGMT. 1023, 1023, 1031, 1036 (2009).

[174] *See* Kline & Rosenberg, *supra* note 171, at 289.

costs, and shipping time during the product development stage. The benefits of low-cost, immediate prototyping are even changing the way large, wealthy firms—which may already have multiple $600,000 industrial 3D printers—approach product development. For example, Ford Motor Company is putting low-cost 3D printers on any engineer's desk that wants one.[175]

After creating and improving numerous prototypes, a company may be ready to sell a finished product at some point. Under traditional manufacturing frameworks, deciding whether to launch a product formally was a risky proposition, because traditional manufacturing techniques are capital intensive, for example, requiring expensive up-front costs such as tooling of machines.[176] If the product needed modification, much or all of these expenses would be lost.[177] Moreover, because mass-manufacturing costs were so expensive, a company would be tempted to manufacture a large number of the new products to achieve economies of scale. If, however, the product was a bust, the unsold merchandise added to sunk costs.

3D printing largely reduces the costs and risks of product launches. With a 3D printer, large investment is not necessary to purchase high-capital cost mass-production machinery. The 3D printer, viewed as capital equipment, can already produce products at a lower cost to consumers than mass manufacturing for short runs, customized products, and a large number of polymer products.[178] In addition, 3D printers are versatile, so if a product needs modification, the printer can print the modification without expensive and slow retooling.

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[175] Stacey Higginbotham, *Ford's Gift to Engineers: MakerBot 3D Printers*, BLOOMBERG BUS. (Dec. 21, 2012, 11:41 AM), http://www.bloomberg.com/news/articles/2012-12-21/fords-gift-to-engineers-makerbot-3d-printers.

[176] Disha Bavishi et al., *Mass Customization of Products*, 5 INT'L J. COMPUTER SCI. & INFO. TECH. 2157, 2157 (2014) ("Mass production is capital intensive and energy intensive, as it uses a high proportion of machinery and energy in relation to workers. However, the machinery that is needed to set up a mass production line is so expensive that there must be some assurance that the product is to be successful to attain profits.").

[177] Emmett W. Eldred & Michael E. McGrath, *Commercializing New Technology-I*, 40 RES. TECH. MGMT. 41, 43 (1997) ("Should the technology ultimately prove unsuitable, and the product development effort be canceled, the product development investment will become a sunk cost.").

[178] Wittbrodt, *supra* note 105, at 713.

3D printers also reduce product launch risk by eliminating the need to mass produce thousands of copies before knowing what demand will be. The printer can radically reduce inventory costs and perform just-in-time manufacturing—printing what customers order essentially in real time.

Finally, 3D printing opens up new product development and manufacturing opportunities. It enables mass customization, because printing modifications is no more difficult than printing multiple identical copies. Perhaps most importantly, 3D printing democratizes product development. Individuals with only a little technical bent can become product designers and manufacturers. Even unsophisticated customers can become the final stage of product developers. There are already, for example, businesses that have a basic design for a product and a web-based app that enables their customers to customize the design for themselves, which the business will then print and ship to customers the next day.[179]

2. Other Technologies

As with basic research and prototyping, basic technologies like inexpensive computing power and the Internet provide platform technologies that reduce the costs of product development in profound ways. The speed of communication and sharing through the Internet greases the wheels of innumerable product development projects. Beyond these background effects, however, countless industries have seen product development costs decrease.

Perhaps no industry has seen costs fall as much as digital-based companies have.[180] For example, in 1999 Naval Ravikant, a cofounder of Epinions, a website for customer reviews, required six months of time and $8,000,000 in venture capital funds to buy computers, license database software, and hire eight programmers before he could launch the website.[181] In contrast,

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[179] Michael Molitch-Hou, *3D Printed Celtic Knots Tie Tradition to New Technology*, 3D PRINTING INDUSTRY (May 7, 2014), http://3dprintingindustry.com/2014/05/07/3d-printing-imaterialise-celtic-knots/; Juho Vesanto, *Design Your Personalized 3D Printable Jewellery Online—Suuz.com*, 3D PRINTING INDUSTRY (June 4, 2013), http://3dprintingindustry.com/2013/06/04/design-your-personalized-3d-printable-jewellery-online-suuz-com/.

[180] Coyle & Green, *supra* note 155 ("Over the past decade, the costs of launching a new technology start-up have fallen precipitously.").

[181] *Testing, Testing*, *supra* note 158.

just eleven years later, he needed only a few weeks and tens of thousands of dollars when he founded AngelList, a social network for startups.[182] Among other things that lowered the startup costs, he used various free software tools for development and cloud computing for the computer power and storage.[183] Numerous startups have leveraged the availability of free, open-source software, cloud-based computing, and fast Internet speeds to lower launch costs.[184]

Once inventors create the prototype of their digital products, they can iteratively update and improve them in real time. They can perform things like testing, user feedback, and product updates through the Internet cheaply and quickly.[185] The inventors can add or subtract whatever server capacity the products require nearly in real time on the cloud.

Beyond digital products, many physical products can progress from prototype to final product much more quickly than in the past. In addition to the above-discussed advantages of 3D printing, new companies are appearing that combine Internet-based networking, industrial design, and manufacturing in one roof. A leading example of this phenomenon is Quirky, a company already mentioned when prototyping was discussed.[186] These companies will take basic ideas and turn them into finished products on behalf of the inventor.[187] The presence of nimble, smaller-scale product developers demonstrates the speed and economy of product development today.

Finally, in the chemical and biological realms, various technologies reduce development costs. Just as biohacker platforms and biomodules aid in invention and prototyping,[188] they can aid in building finished products. One company even offers an inexpensive method to print DNA.[189] Similarly,

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182 *Id.*

183 *Id.*

184 Coyle & Green, *supra* note 155, at 155–57.

185 Websites such as usertesting.com provide a crowdsourcing means for testing products. *See, e.g.*, USERTESTING, http://www.usertesting.com/about-us (last visited Apr. 2, 2016).

186 *See supra* note 159 and accompanying text.

187 Lohr, *supra* note 160 (describing Quirky's business).

188 *See supra* notes 163–165 and accompanying text.

189 Conner Forrest, *Cambrian Genomics Laser Prints DNA To Rewrite the Physical World*, TECHREPUBLIC (Nov. 12, 2014, 5:00 AM), http://www.techrepublic.com/article/cambrian-genomics-laser-prints-dna-to-rewrite-the-physical-world/.

molecular modeling is not only useful to identify lead pharmaceutical compounds, but also to help optimize lead compounds into a molecule suitable for clinical trials.[190]

D. Obtaining Funding

In reality, the task of obtaining funding continues throughout the whole process. Obviously, funding is extremely important because without some source of capital, most innovations cannot proceed.[191] Start-ups incur costs in the stages mentioned previously and in marketing and distribution, discussed in the next Section. Start-ups must pay employees and consultants and purchase materials and equipment. While people tend to think of funding in terms of start-ups receiving venture capital funding, projects developed within large firms also need financial support from the firm.[192] Any decrease in the costs of the innovation cycle will tend to make innovation easier at start-ups and large firms alike.

Outside funding can come from a variety of sources, but the quintessential source—at least for new companies attempting to overcome capital constraints—is venture capital.[193] Other traditional sources include government grants, angel investors, and even friends and family. For innovations developed within an existing large firm, the source of funding is most often the firm itself.

One innovation in funding is the advent of crowdfunding, which is the practice of obtaining capital, usually in relatively small individual amounts, from a large number of people, typically through the Internet.[194] The concept is disrupting the established business of funding innovations and is empowering

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[190] Watson, *supra* note 166, at 27.

[191] Maclaurin, *supra* note 87, at 108 ("Yet a nation could contribute significantly to pure science and to invention but remain stagnant if too small a proportion of the capital supply in the country were channeled into new developments.").

[192] Eldred & McGrath, *supra* note 177, at 42 ("In order for a technology to receive appropriate funding, researchers and business managers must convince each other that the technology holds real economic promise.").

[193] PAUL A. GOMPERS & JOSH LERNER, THE MONEY OF INVENTION: HOW VENTURE CAPITAL CREATES NEW WEALTH 11 (2001).

[194] Sean M. O'Connor, *Crowdfunding's Impact on Start-up IP Strategy*, 21 GEO. MASON L. REV. 895, 897 (2014).

individuals and small businesses.[195] It is not only individuals who are interested in buying the future product who contribute; more formal investors will contribute in hopes of making a return on their investment.[196] Many crowdfunding platforms exist already, including Kickstarter, Indiegogo, Fundable, and Peerpackers.[197]

Although crowdfunding directly impacts the funding process, new and emerging technologies such as 3D printing and the Internet have an important indirect effect.[198] The central point here is that as the costs of innovation decrease, the amount of outside capital needed to finance the innovation decreases. As the sums become smaller, the need for traditional venture capital decreases.[199] Instead, innovators can raise adequate capital from alternative sources, such as alternative venture capital-like funding, crowdfunding, and even friends and family.[200] This has a two-fold effect in reducing barriers to innovation. First, it is generally easier to raise smaller rather than larger amounts of money. Second, less formal avenues for obtaining funding are less cumbersome and intimidating, meaning that innovators are less likely to give up.

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[195] Maria Doyle, *Crowdfunding Spurs Innovation in Science, Technology, and Engineering*, FORBES (Oct. 23, 2013, 10:09 AM), http://www.forbes.com/sites/ptc/2013/10/23/crowdsourcing-spurs-innovation-in-science-technology-and-engineering/ ("Crowdfunding . . . [is] disrupting the way enterprises, entrepreneurs, non-profits, and individuals raise capital . . . .").

[196] *See generally* THOMAS E. VASS, ACCREDITED INVESTOR CROWDFUNDING: A PRACTICAL GUIDE FOR TECHNOLOGY EXECUTIVES AND ENTREPRENEURS (2014) (describing strategies for technology companies to raise money from accredited investors through crowdfunding).

[197] *See Directory of Sites*, CROWDSOURCING.ORG, http://www.crowdsourcing.org/directory (last visited Apr. 2, 2016) (featuring a directory of crowdsourcing platforms).

[198] It is also important to note that when pitching product ideas to investors or management, having a functional 3D prototype in hand—or in a digital form one can email to investors to print—is advantageous. TOM KELLEY WITH JONATHAN LITTMAN, THE ART OF INNOVATION 112 (2001) ("But a prototype is almost like a spokesperson for a particular point of view, crystallizing the group's feedback and keeping things moving." (emphasis omitted)).

[199] *See* Coyle & Green, *supra* note 155, at 157.

[200] *See id.* at 157–58.

E. Marketing and Distribution

Once a business decides it will launch a product, it must develop a marketing campaign and distribution strategy.[201] Marketing includes at least the process of promoting goods or services to prospective customers through advertising and other promotional methods.[202] Distribution relates to how a company will ensure that prospective customers are able to locate, obtain, and use its products and services.[203]

1. 3D Printing

3D printing technology is likely to have rather minor effects on product promotion but will bring a sea of change to distribution. In a world where virtually every consumer owns a cheap but sophisticated 3D printer at home, physical distribution costs can be virtually eliminated—other than for the printer feedstock. Instead, a seller need only transfer the CAD file to the buyer, who then prints the object at home.

The popular press speculates feverishly that the technical advances in 3D printing could result in a "third industrial revolution" governed by mass customization and local, digital-based manufacturing.[204] Technical commentators likewise discuss how radically the distribution models will change, noting also that economic models may change.[205] Thus, for example, thousands of individuals around the globe can freely copy a single CAD design of a high-value product like a water pump

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[201] *See* Kline, *supra* note 90, at 37 fig.2 (showing "distribute and market" as the final stage of innovation).

[202] JAMES L. BURROW, MARKETING 6 (3d ed. 2012).

[203] *Id.*

[204] *See, e.g.*, *The Third Industrial Revolution*, ECONOMIST (Apr. 21, 2012), http://www.economist.com/node/21553017 (investigating in a special issue what the editors refer to as a third industrial revolution brought on by digital manufacturing and 3D printing).

[205] *See generally* NEIL A. GERSHENFELD, FAB: THE COMING REVOLUTION ON YOUR DESKTOP—FROM PERSONAL COMPUTERS TO PERSONAL FABRICATION (2008); HOD LIPSON & MELBA KURMAN, FABRICATED: THE NEW WORLD OF 3D PRINTING (2013); R.E. DeVor et al., *Transforming the Landscape of Manufacturing: Distributed Manufacturing Based on Desktop Manufacturing (DM)^2*, 134 J. MANUFACTURING SCI. & ENGINEERING (2012) (examining a new paradigm in the world of manufacturing—distributed manufacturing based on desktop manufacturing—what they refer to as (DM)^2); J.M. Pearce et al., *3-D Printing of Open Source Appropriate Technologies for Self-Directed Sustainable Development*, 3 J. SUSTAINABLE DEV. 17, 17 (2010) (discussing the use of 3D printers to help the developing world to manufacture); *see also* Pearce, *supra* note 149, at 430.

part and can then use 3D printing to make the device for only the cost of raw materials.[206] For those unable or unwilling to buy a 3D printer, many online 3D printer services have already been developed that will print the item for a buyer and either mail it or provide it for pick-up.[207]

Some doubt whether the technology will ever achieve such dramatic impacts.[208] It is true that today, even with hundreds of thousands of openly available 3D printable designs, only a relatively tiny fraction of products are completely 3D printable. The low-cost RepRap3D printers discussed in this Article print primarily in plastics—polylactic acid ("PLA") and acrylonitrile butadiene styrene ("ABS")—which is clearly limiting.[209]

On the contrary, many other materials have been used—including ceramics, flexible polymers, and wood-fiber composites—at the do-it-yourself level,[210] much more sophisticated 3D printing materials have been shown in the academic literature,[211] and it appears clear that a much wider selection of materials will be made possible for 3D printers in the near future.[212] For example, RepRaps capable of printing in

[206] *See* Pearce, *supra* note 149, at 428.

[207] *See, e.g.*, MAKEXYZ, http://www.makexyz.com/ (last visited Apr. 2, 2016); PONOKO, https://www.ponoko.com/ (last visited Apr. 2, 2016); SHAPEWAYS, http://www.shapeways.com/ (last visited Apr. 2, 2016).

[208] For example, Foxconn President Terry Gou says that "3D printing is a gimmick," explaining, "Foxconn had been using 3D printing for nearly three decades. However, 3D printing is not suitable for mass production, and it [does not] have any commercial value." *'3D Printing Is Just a Gimmick,' Says Foxconn President Terry Gou*, 3DERS.ORG (June 26, 2013), http://www.3ders.org/articles/20130626-3d-printing-is-just-a-gimmick-says-foxconn-president-terry-gou.html.

[209] *RepRap Materials*, APPROPEDIA, http://www.appropedia.org/RepRap_materials (last modified June 13, 2014).

[210] *Id.*

[211] *See, e.g.*, Thomas A. Campbell & Olga S. Ivanova, *3D Printing of Multifunctional Nanocomposites*, 8 NANO TODAY 119, 119 (2013); Gavin MacBeath, Angela N. Koehle & Stuart L. Schreiber, *Printing Small Molecules as Microarrays and Detecting Protein—Ligand Interactions en Masse*, 121 J. AM. CHEMICAL SOC'Y 7967, 7967 (1999); A. Ovsianikov et al., *Laser Printing of Cells into 3D Scaffolds*, 2 BIOFABRICATION 1, 5 (2010); Harpreet Singh, Paul E. Laibinis & T. Alan Hatton, *Synthesis of Flexible Magnetic Nanowires of Permanently Linked Core-Shell Magnetic Beads Tethered to a Glass Surface Patterned by Microcontact Printing*, 5 NANO LETTERS 2149, 2149 (2005).

[212] Emily J. Hunt et al., *Polymer Recycling Codes for Distributed Manufacturing with 3-D Printers*, 97 RESOURCES CONSERVATION & RECYCLING 24, 24–25 (2015).

metal are just now emerging,[213] and a low-cost printer capable of even printing in steel[214] and aluminum[215] with reusable substrates is openly available.[216] Much like the ubiquity of personal computers catalyzed a proliferation of software, the coming ubiquity of 3D printers will create strong demand for various printer feed stock. As the materials and designs multiply, particularly if they are open-source, it will result in a much wider range of completely 3D-printable products, thus reducing the costs and the risks of distribution.

2. Other Technologies

The recent technology that most directly affected innovation in marketing and distribution is the Internet. On the marketing front, it made possible online stores and advertising. The Internet, and related advances in data gathering and processing, has enabled companies to collect detailed consumer information to tailor their marketing strategies.[217] Add to the Internet the rise of smart phones, and now companies can exploit various social media avenues, including Twitter, YouTube, and Facebook, without large marketing budgets.[218]

In the distribution realm, the Internet helped give rise to innovations such as paperless delivery of tickets and payments[219] and quick delivery of physical goods.[220] For digital-based

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[213] Jorge Mireles et al., *Development of a Fused Deposition Modeling System for Low Melting Temperature Metal Alloys*, 135 J. ELECTRONIC PACKAGING 011008-1, 011008-4 (2013).

[214] Gerald C. Anzalone et al., *A Low-Cost Open-Source Metal 3-D Printer*, 1 IEEE ACCESS 803, 803 (2013).

[215] Amberlee S. Haselhuhn et al., *In Situ Formation of Substrate Release Mechanisms for Gas Metal Arc Weld Metal 3-D Printing*, 226 J. MATERIALS PROCESSING TECH. 50, 50 (2015).

[216] *Id.* at 50–51, 58.

[217] Yongmin Chen, *Marketing Innovation*, 15 J. ECON. & MGMT. STRATEGY 101, 101 (2006).

[218] DAN ZARRELLA, THE SOCIAL MEDIA MARKETING BOOK 1–2, 7 (2010).

[219] People now remotely print—or simply use electronic copies of—airline boarding passes, tickets to movie theaters, and the like.

[220] *See generally* Joseph P. Bailey & Elliot Rabinovich, *Internet Book Retailing and Supply Chain Management: An Analytical Study of Inventory Location Speculation and Postponement*, 41 TRANSP. RES. PART E 159 (2005); Jack D. Becker, Ted Farris & Phil Osborn, *Electronic Commerce and Rapid Delivery: The Missing "Logistical" Link*, 1998 AM. CONF. INFO. SYSTEMS PROC. 272, *available at* http://aisel.aisnet.org/amcis1998/94 (predicting the future of quick delivery for electronic commerce purchases). Readers may be familiar with Amazon's "Prime" delivery, which provides two-day shipping on many goods. *See Amazon Prime*,

innovation, the presence of increased Internet speeds, ubiquitous mobile computing, and social media networks all allow companies to distribute their products and services rapidly and at a potentially unlimited scale.[221] Of course, cloud computing is itself a powerful example of dramatically reduced distribution costs—the software is stored remotely and delivered only digitally.

F. Addressing Concerns

In sum, technology is drastically lowering the costs of innovation across a wide range of sectors. Not all the technology, of course, is yet mature. However, it is already having profound effects, and these will grow.

This Section recognizes potential criticisms of this Article's technology discussion. Specifically, it can be questioned whether this Article cherry-picked the technologies that most support its recommendations while ignoring contrary evidence of increased innovation costs in other technologies. The authors freely admit that the technologies described herein represent some of the most powerful examples of decreased innovation costs. But rather than cherry-picking them to support this Article's recommendations, the recommendations follow from an understanding of technology and its effects. Simultaneously, the authors are not aware of any technology that has drastically increased the costs of innovation in a meaningful way. Thus, the Article asserts that the average cost of innovation has decreased and will continue to do so dramatically.

Second, one can ask: If inventions have been lowering the costs of innovation throughout history, why is this moment the right moment to weaken patent rights? It is true that many inventions through history have lowered the costs of innovation in one way or another. The microscope, the integrated circuit, and the internal combustion engine represent just a few inventions that have had dramatic impacts on society and innovation. There are at least two responses to this criticism. First, some of the key innovations addressed here differ from many previous innovations in terms of their net effects on

AMAZON, http://www.amazon.com/gp/prime/ref=footer_prime (last visited Apr. 2, 2016).

[221] Coyle & Green, *supra* note 155, at 156–57.

innovation costs. For example, the internal combustion engine gave rise to new technology such as cars and planes, but that technology required huge capital costs and significant expertise. In contrast, 3D printing and the Internet are accessible to teenagers, and many of the innovations that follow from them are relatively low in cost. Although some earlier innovations might parallel 3D printing and the Internet more closely than the internal combustion engine, this leads to the second response to the criticism. Namely, the criticism may prove too much: If the costs of innovation have been lowering for decades, then perhaps lawmakers should have weakened patent rights long ago.

III. ADAPTING THE PATENT SYSTEM TO THE NEW AGE OF INNOVATION

In the preceding Part, this Article demonstrated that the costs of innovation are decreasing, often dramatically, across many technology sectors. In this Part, it explores the consequences of this phenomenon, arguing that the decreased costs of innovation impel a weakening of the patent system. This prescription follows not only from the traditional utilitarian incentive theory of the patent system, but also from other theories. After presenting the case for a weaker patent system, this Part then provides concrete observations about how the patent system should be changed. First, it queries what magnitude of change the patent system requires. Second, it proposes methods of achieving that change.

The case for a weaker patent system holds on any view of the patent system. Consider first the most dominant theory, the incentive-to-invent theory, which was described briefly in the Introduction. This theory posits that inventors need patents to be able to recoup their R&D costs and make a profit without free-riders undercutting their price.[222] Note that under this theory, patents are granted for inventions, and inventing is an early stage in the innovation cycle.[223] Thus, patents most directly incentivize basic research and inventing.[224] As this Article has

[222] *See supra* note 2 and accompanying text.

[223] Christopher A. Cotropia, *The Folly of Early Filing in Patent Law*, 61 HASTINGS L.J. 65, 68–70, 72–81 (2009); Sichelman, *supra* note 8, at 365–66.

[224] Sichelman, *supra* note 8, at 366 ("Strictly speaking, patent laws provide direct incentives to *invent*, but not generally to *innovate*.").

demonstrated, technologies are reducing both of these costs. Following the economic model of the incentive theory therefore suggests that inventors need less incentive because they need to recoup fewer costs. To lower the incentives, one should weaken the patent system, because doing so will align incentives with needs.

Weakening patent rights has the important salutary effect of decreasing their harmful effects. First, consider the deadweight loss harm associated with monopoly pricing.[225] Weaker patents diminish this deadweight loss by reducing the power of the patentee. For example, if lawmakers weaken patents by shortening their term, they shorten the period of monopoly pricing. Alternatively, if lawmakers weaken patents by narrowing their scope, there is a greater chance that inventors will develop viable, noninfringing substitutes.

Second, consider the harm associated with impeding follow-on innovation. As discussed in the Introduction, broad patents can inhibit follow-on innovation where the follow-on innovation infringes the first patent.[226] Although the improver can theoretically obtain a mutually beneficial license from the owner of the first patent, various transaction costs often prevent this.[227] Where, however, patents are weakened, the friction against follow-on inventions is correspondingly weakened. For example, a shorter patent life would shorten the restrictions on follow-on innovation. Similarly, narrower patents would allow more follow-on innovation to avoid infringing the first patent.

An alternate theory of the patent system, the prospect theory, also suggests that lawmakers should weaken patents as innovation costs decrease. The prospect theory arose in part from an appreciation that patents provide not only direct incentives for basic research and invention, but also indirect incentives for postinvention expenditures—for example, the commercialization expenses of product development and

[225] For a discussion of monopoly pricing, see LANDES & POSNER, *supra* note 6, at 22–23; see also *supra* note 7 and accompanying text.

[226] Merges & Nelson, *supra* note 1, at 870 ("[B]road patents could discourage much useful research.").

[227] *See id.* at 874 n.146 (cataloguing literature showing the high costs of licensing); Sichelman, *supra* note 8 (reviewing transaction costs that can stifle commercialization).

marketing.[228] Recognizing the indirect nature of these incentives, the prospect theory and related commercialization theories[229] suggest that patents might underincentivize commercialization expenditures unless patents are sufficiently strong.[230] In other words, patents need to be stronger than the necessary amount merely to incentivize inventions; they need to be strong enough to incentivize commercialization costs.[231] The prospect theory has been much debated,[232] but to the extent it and related commercialization theories are accurate, they support this Article's call for weaker patents. Simply put, the decreased costs of product development, marketing, and distribution identified in Part II demonstrate that inventors need less incentive to incur those costs. Where inventors need lower incentives, lawmakers can weaken patents, thereby lessening the harms they cause while maintaining optimal incentives for innovation.

Capitalizing on insights about postinvention costs of innovation, others have championed more radical changes to the patent system. Most recently, Professor Ted Sichelman has proposed a particular kind of commercialization patent that would directly incentivize postinvention commercialization efforts regardless of the presence of a traditional invention-based patent.[233] Such a system would provide, however, the possibility for monopoly prices tied to a specific commercial embodiment.[234]

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[228] Sichelman*, supra* note 8, at 367–68; *see also* Robert P. Merges, *Commercial Success and Patent Standards: Economic Perspectives on Innovation*, 76 CALIF. L. REV. 803, 809 (1988) ("[T]he patent system rewards *innovation* only indirectly, through the granting of patents on *inventions*.").

[229] Other works presenting commercialization theories include Michael Abramowicz, *The Danger of Underdeveloped Patent Prospects*, 92 CORNELL L. REV. 1065 (2007); Michael Abramowicz & John F. Duffy, *Intellectual Property for Market Experimentation*, 83 N.Y.U. L. REV. 337 (2008); and F. Scott Kieff, *Property Rights and Property Rules for Commercializing Inventions*, 85 MINN. L. REV. 697 (2001).

[230] *See supra* note 5 and accompanying text.

[231] *See* John F. Duffy, *Rethinking the Prospect Theory of Patents*, 71 U. CHI. L. REV. 439, 440 (2004) ("Kitch's justification for the patent system was thus forward-looking: The function of the patent system is to encourage investment in a technological prospect *after* the property right has been granted.").

[232] *Id.* at 441–42 (describing criticisms).

[233] Sichelman, *supra* note 8, at 400–10.

[234] Professor Sichelman seeks to avoid invention patents' impediment to follow-on innovation by requiring a very narrow commercializing claim scope. *Id.* at 401. However, he recognizes the claims must allow for some penumbra of protection beyond literal infringement. *Id.* at 401–02. The broader the protection, the greater the impediment to follow-on innovation.

The monopoly price would lead to deadweight loss in a manner similar to a traditional patent, and thus the strength of any such patent should be tailored to the need to recoup costs. Hence, just as with other economic justifications of patents, the necessary strength of any such patent will decrease as the costs of postinvention innovation costs decrease. Given the administrative costs of initiating such a radical new system, the observations about innovation costs much diminish the case for such a new system.

Finally, this Article's observations about decreased innovation costs also impact noneconomic theories of the patent system. For example, a Lockean natural rights theory of patent law suggests that inventors deserve patents as a reward for their labor.[235] Under such a theory, however, the size of the reward should be proportional to the labor contributed.[236] Because the average costs—here, labor—of innovation are decreasing, the deserved reward should likewise be smaller, in the form of a weaker patent.

Thus, in almost any view of the patent system, a decrease in innovation costs militate in favor of weakening the patent system. That said, questions remain regarding the magnitude of the change to the patent system and the method of effecting that change. These questions are explored below.

A. *Magnitude of Change to the Patent System*

Part II of this Article provided a broad assessment of how recent technologies have reduced innovation costs. Yet this Article is not empirical in nature, and the authors do not know the precise values of the reductions to innovation costs. Even if we did, we would not solve the problem of the patent system's immense complexity.[237] Nevertheless, our insight is that a broad and growing shift in innovation costs has occurred such that the average cost of innovation has decreased significantly.

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[235] Hughes, *supra* note 4, at 297–310.

[236] LAWRENCE C. BECKER, PROPERTY RIGHTS: PHILOSOPHIC FOUNDATIONS 53–54 (1977); Lawrence C. Becker, *Deserving To Own Intellectual Property*, 68 CHI.-KENT. L. REV. 609, 625 (1993) ("And what counts as a 'proportional' return is limited by an equal sacrifice principle: the sacrifice we make in satisfying your desert-claim should not exceed your level of sacrifice in producing (our part of) the good.").

[237] *See supra* notes 17–18 and accompanying text.

As a starting point, however, this Article suggests a change that is significant enough so that one can ascertain and study its effects. Too small of a change would be lost in the complex noise of the patent system. Hence, this Article recommends a change, or set of changes, that would be roughly equivalent to weakening patents by at least twenty-five percent to fifty percent.

The remainder of this Section analyzes various key additional considerations that policymakers should weigh when considering the magnitude of the change to the patent system.

1. Nonmonetary Incentives To Innovate Favor a Weaker Patent System

A growing body of literature using insights from psychology and sociology to study the patent system strengthens the argument for weaker patents.[238] One insight from this literature is that people engage in innovative activities not only for pecuniary reasons, but also for nonmonetary reasons, including intellectual challenge, recognition, the joy of inventing and solving problems, improving social welfare, or the desire for control and responsibility.[239] Thus, dampening monetary incentives will generally not have a directly proportional effect on overall incentives to innovate.

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[238] *See generally* Dennis D. Crouch, *The Patent Lottery: Exploiting Behavioral Economics for the Common Good*, 16 GEO. MASON L. REV. 141 (2008); Jeanne C. Fromer, *A Psychology of Intellectual Property*, 104 NW. U. L. REV. 1441 (2010); William Hubbard, *Inventing Norms*, 44 CONN. L. REV. 369 (2011); Eric E. Johnson, *Intellectual Property and the Incentive Fallacy*, 39 FLA. ST. U. L. REV. 623 (2012); Gregory N. Mandel, *To Promote the Creative Process: Intellectual Property Law and the Psychology of Creativity*, 86 NOTRE DAME L. REV. 1999 (2011); Laura G. Pedraza-Fariña, *Patent Law and the Sociology of Innovation*, 2013 WIS. L. REV. 813 (2013); Bair, *supra* note 1.

[239] *E.g.*, Hubbard, *supra* note 238, at 373 ("[M]any Americans share . . . 'inventing norms,' which are social attitudes of approval for successful invention."); Henry Sauermann & Wesley M. Cohen, *What Makes Them Tick? Employee Motives and Firm Innovation*, 56 MGMT. SCI. 2134, 2134, 2150 (2010) (citing numerous sources that support the hypothesis that inventors are motivated by nonpecuniary rewards).

Pecuniary and nonpecuniary motivations can often work together synergistically.[240] In those cases, the monetary promise of a patent and the nonmonetary encouragers of invention, such as love of inventing or desire for recognition, both incentivize innovation. A key consequence of this observation is that, as the patent system weakens, the proportions of monetary and nonmonetary incentives change. The following chart demonstrates this phenomenon on an assumption that a decrease in patent strength by fifty percent decreases monetary incentives by fifty percent but does not affect nonmonetary incentives.[241]

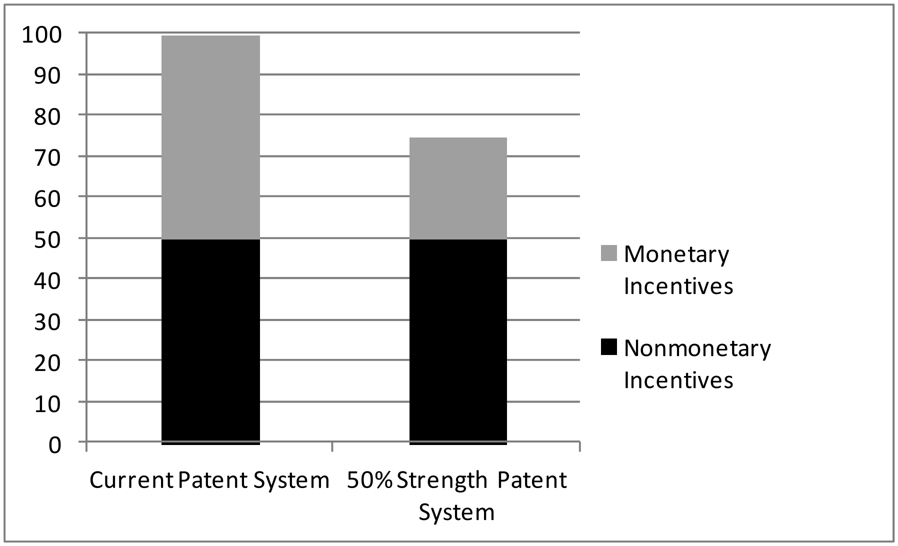

Chart 1: Effect of Changing Monetary Incentives

[240] Mandel, *supra* note 238, at 2000 ("Experiments reveal that certain types of extrinsic motivation can enhance intrinsic motivation, although the line that separates positive from negative extrinsic influences is subtle."). Note that sometimes offering monetary incentives can have the opposite effect. *See* Christopher Buccafusco et al., *Experimental Tests of Intellectual Property Laws' Creativity Thresholds*, 92 TEX. L. REV. 1921, 1937–39 (2014) (describing how extrinsic motivators sometimes undermine creativity); Harvey S. James Jr., *Why Did You Do That? An Economic Examination of the Effect of Extrinsic Compensation on Intrinsic Motivation and Performance*, 26 J. ECON. PSYCHOL. 549, 551 (2005); Johnson, *supra* note 238, at 671–76 (suggesting that patents are rarely, if ever, necessary to incentivize invention).

[241] As described below, this may be an oversimplification because adjusting patent strength may affect nonmonetary incentives. *See infra* Chart 1 and accompanying text.

In the chart, the lighter area at the top of the bar graph represents motivation from monetary incentives, and the darker area below represents motivation from nonmonetary incentives. The left column represents the current patent system, with a simple assumption that the inventor's motivation to invent is split exactly in half: Half is from the monetary incentives promised under current patent strength and half is from a collection of nonmonetary incentives. In total, the column on the left shows 100 "units" of motivation. The column on the right demonstrates what would happen if lawmakers weaken patents by fifty percent, assuming that the reduction in strength directly correlates with a reduction in monetary incentive. Under this scenario, the inventor continues to have fifty units of motivation from nonmonetary sources, but only twenty-five units from monetary sources. Thus, monetary motivation only represents thirty-three percent of the inventor's motivation. Importantly, however, whereas patents were weakened by fifty percent, the inventor's overall motivation only decreased by twenty-five percent.

Chart 1 graphically illustrates that weakening the patent system does not necessarily result in a directly proportional weakening of incentives to innovate. Further, if we assume technology has reduced innovation costs by fifty percent, then weakening patents by fifty percent will actually leave a surplus of motivation for innovation—meaning that the incentive remains above fifty percent—compared to the situation before the costs of innovation decreased. This suggests that lawmakers need not be too hesitant to weaken patents, and that the amount by which they weaken patents need not be too conservative.

Psychology and sociology provide additional insights into the optimal magnitude of change to the patent system's strength. To understand these insights, it is necessary to distinguish between intrinsic and extrinsic motivators. In the language of psychology, monetary rewards represent an extrinsic motivator in that they originate outside the inventor.[242] Many nonmonetary reasons, such as the love of inventing, represent intrinsic motivations, meaning that they come from within the inventor.[243]

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[242] Mandel, *supra* note 238, at 2008.
[243] *Id.*

Gregory Mandel has noted that research into the psychology of creativity shows that "intrinsically motivated work is more likely to produce more creative output than extrinsically motivated work."[244] The more inventive work is intrinsically motivated, the more likely it will bear inventive fruit.[245] Mandel's insight suggests that patant law must be carefully calibrated so that the extrinsic, monetary incentives do not dominate intrinsic motivation.[246] This suggests that we should not allow the monetary incentives of a patent to be too strong or else the extrinsic motivation will dominate.

If patents maintain the same strength as innovation costs decrease, financial returns of increased profit will represent stronger monetary incentives. Thus, to avoid allowing the external motivation of patents to dominate intrinsic motivations, which would result in less fruitful inventive activity, lawmakers should weaken patents as innovation costs decrease.

Another important insight from the behavioral literature relates to inventing norms. William Hubbard describes various "inventing norms," which are social norms that encourage invention, such as love of problem solving, a high view of inventors, and collective pride in invention and technological achievement.[247] In Hubbard's view, financial rewards and inventing norms can sometimes work together to encourage invention.[248] For example, protecting inventions with patents, which offer financial rewards, can reinforce inventing norms by signaling a value judgment in favor of inventions.[249]

Hubbard notes that if we abolished patents altogether, it "could be viewed as evidence that invention is no longer important in America, thereby reducing the social incentives to pursue technological discoveries."[250] On the contrary, going in the opposite direction by increasing the strength of patents could also reduce the effects of inventing norms by signaling patents to be nothing more than objects "of self-interested greed, rather

[244] *Id.* at 2007–08.
[245] *Id.* at 2010.
[246] Mandel focuses on framing activities as intrinsically oriented. *Id.* at 2012. However, it is reasonable to believe that stronger patents will tend to dominate intrinsic incentives compared to weaker patents.
[247] Hubbard, *supra* note 238, at 378–87.
[248] *Id.* at 408.
[249] *Id.* at 392–93.
[250] *Id.* at 408.

than praiseworthy invention."[251] Hubbard's primary insight is that any change in the strength of patents should be studied not only through the lens of the rational economic actor, but also through inventing norms.[252] To the extent that inventing norms can be measured and predicted, Hubbard's observations suggest that this Article's proposed reforms should not have tremendous positive or negative effects on inventing norms. The weakened patents may signal that patent law is not only about money, and the fact that the patent system would remain demonstrates that America continues to value patents.

2. Decreased Costs and Speed of Copying Favor Retaining a Patent System

Both imitators and innovators can use the technologies that lower innovation costs. Recall that without patents, imitators have an advantage over innovators in that they avoid some of the R&D costs. Imitators can wait and learn from the invention, product development, and commercialization efforts of innovators and then free ride by copying only the successful features. Free riding is not always possible and is often imperfect, but at least some degree of imitation is widely prevalent and represents a very important aspect of the marketplace.[253] It is important, therefore, to analyze the impacts of new technologies on imitation.

In the absence of patents or other means of protection, imitation can tend to discourage innovation. The new technologies described in this Article will often reduce the costs of imitation. For example, if an imitator obtains another company's CAD file of a 3D-printable item, the imitator no longer needs to reverse engineer the item; it can simply print it.[254] Even

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[251] *Id.* at 404.

[252] *Id.* at 412.

[253] STEVEN P. SCHNAARS, MANAGING IMITATION STRATEGIES: HOW LATER ENTRANTS SEIZE MARKETS FROM PIONEERS 1 (1994) (noting that imitation is more abundant than innovation); ODED SHENKAR, COPYCATS: HOW SMART COMPANIES USE IMITATION TO GAIN A STRATEGIC EDGE (2010); Roin, *supra* note 14, at 689 ("Indeed, firms routinely capitalize on their rivals' R&D by engaging in competitive imitation."). Some think imitation should occur more often. *E.g.*, Oded Shenkar, *Imitation Is More Valuable Than Innovation*, HARV. BUS. REV., Apr. 2010, at 1, *available at* http://i2ge.com/wp-content/uploads/2012/01/Imitation-instead-of-innovation.pdf (finding imitation to be a great source of progress).

[254] This assumes that any patents, copyrights, or trade secrets do not protect the CAD file.

where the imitator must develop its own product through reverse engineering, 3D printing and other technology can reduce the costs of prototyping and product production.

When the costs of copying are low compared to the costs of innovating, the case for patent protection is stronger. This might suggest that the new technologies, which reduce imitation costs, make a stronger case for patents. However, the need for patents would only increase if the costs of copying decreased proportionally more than the costs of innovation. For example, assume that before these new technologies, it costs $1,000,000 dollars to innovate a given product and $500,000 to copy it. Assume further that after these technologies, the innovation costs were $500,000 and copying costs were $250,000. In this scenario, the cost of copying remained one-half of the innovation costs, suggesting that the net effect on the need for patents is zero.

The costs of copying, however, vary across industries and products. Studies from the 1980s tend to show that the costs of copying were, on average, about three-quarters to one-half the costs of innovating.[255] However, the same studies show that there is a great deal of variation in these costs so that many imitations fall above or below the average.[256] The high rate of variation in the data counsels caution in drawing too firm a conclusion about the overall effect of new technologies on imitation. Given that previous studies occurred even before the Internet, this is an area where updated empirical work might shed significant light on technologies' effects on imitation.

Another aspect of imitation, however, probably allows for firmer conclusions. An important factor for determining whether a copycat product will be successful in competing with or overtaking the original is the time it takes to develop and introduce the copycat product.[257] Assuming no substitute goods

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[255] Richard C. Levin et al., *Appropriating the Returns from Industrial Research and Development*, 1987 BROOKINGS PAPERS ON ECON. ACTIVITY 783, 809 (1987); Edwin Mansfield et al., *Imitation Costs and Patents: An Empirical Study*, 91 ECON. J. 907, 909 (1981) (average cost of innovation was about two-thirds the cost of creation); Najib Harabi, *Innovation Versus Imitation: Empirical Evidence from Swiss Firms*, MUNICH PERSONAL REPEC ARCHIVE 1, 12 (1991), https://mpra.ub.uni-muenchen.de/26214/2/MPRA_paper_26214.pdf.

[256] Levin, *supra* note 255, at 808–09; Mansfield, *supra* note 255.

[257] *See* Christina L. Brown & James M. Lattin, *Investigating the Relationship Between Time in Market and Pioneering Advantage*, 40 MGMT. SCI., 1361, 1362

exist, lead-time advantages for original innovators allow them to charge higher prices, establish a reputation, and take advantage of lock-in effects.[258] Lock-in effects can arise when customers adopt a product and it would be costly for them to switch, such as when a customer becomes familiar with a product's look and feel—remember the difficulty of switching between a Mac and a PC—or when the customer has sunk ancillary costs into adopting a product.[259] Additionally, a positive network effect, which is the phenomenon of a good becoming more valuable to each user as more people use it, can exponentially increase lead-time advantage.[260]

Interestingly, therefore, speedy copycat deployment can diminish lead-time advantages independent of the costs of innovation and copying. This fact warrants further analysis because the technologies that reduce the costs of innovation can likewise significantly reduce the time it takes to imitate an invention and deliver a final product to consumers. Where a product can be digitally copied and delivered, such as software or a 3D-printable object, the imitation time can be virtually zero.[261]

The decrease in lead-time for copycat products implies that patents remain useful in protecting innovation and should not be abolished. This Article's proposal meshes with this observation, as it suggests only weakening, not abolishing, patents.

3. Global Competitiveness Concerns Favor Weakening Patents

Opponents of weaker patents make two additional related arguments. First, they argue weaker patents will cause the United States to lose global competitiveness, and second, they will cause companies to leave the United States in favor of countries with stronger patents.[262] The argument that the

(1994) (finding that pioneering advantage is related to a brand's length of time in the market).

[258] Marvin B. Lieberman & David B. Montgomery, *First-Mover Advantages*, 9 STRATEGIC MGMT. J. 41, 46 (1988).

[259] *See id.*

[260] Marvin B. Lieberman & David B. Montgomery, *First-Mover (Dis)Advantages: Retrospective and Link with the Resource-Based View*, 19 STRATEGIC MGMT. J. 1111, 1113 (1998).

[261] This assumes the copier has the program's source code or the printable product's CAD file and ignores the potential of protection through digital rights management.

[262] *E.g.*, Gene Quinn, *A Patent Eligibility in Crisis: A Conversation with Bob Stoll*, IPWATCHDOG (Oct. 10, 2014), http://www.ipwatchdog.com/2014/10/10/a-

United States will lose competitiveness is flawed. First, in certain industries, such as where innovation costs are low or alternate means of protection exist, patents are not perceived as very important.[263] Weaker patents might not bother these industries, and they might even increase competitiveness. Indeed, some industry actors actively seek a weaker patent system.[264] Other major innovators such as Tesla Motors have begun to open source their patents[265] on electric vehicles and were then emulated by more traditional car manufactures such as Ford.[266]

Second, arguments against weaker patents fail to realize the global nature of the patent system. As an initial matter, for weaker patents to disadvantage the United States' global competitiveness, the effect of weaker patents must apply to domestic businesses more than foreign ones. William Hubbard has pointed out that the majority of United States patents are issued to foreign inventors, and thus any increase in the value of United States patents will disproportionately benefit non-United

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patent-eligibility-in-crisis-a-conversation-with-bob-stoll/id=51616/ ("[Courts] seem to be not considering the fact that the United States is leading in many [technologies where patents are being weakened.] . . . [You are] going to start to see some of these companies . . . start to move to other jurisdictions[;] . . . [you are] going to see jobs leaving the United States and research going overseas . . . ." (quoting interview with Bob Stoll, former Comm'r for Patents, U.S. PTO (Sept. 4, 2014))); Frank Cullen, *Why We Shouldn't Go Soft on Software Protection*, GLOBAL INTELL. PROP. CENTER (Oct. 21, 2014), http://www.theglobalipcenter.com/why-we-shouldnt-go-soft-on-software-protection/ ("[W]eakening patent protection would weaken our global competitiveness and harm American companies.").

[263] *See* Stuart J.H. Graham et al., *High Technology Entrepreneurs and the Patent System: Results of the 2008 Berkeley Patent Survey*, 24 BERKELEY TECH. L.J. 1255, 1290 (2009) (showing survey results of start-up companies indicating that software company executives consider patents less important than gaining first mover advantage, acquisition of complementary assets, copyrights, trademarks, secrecy, and making software difficult to reverse engineer).

[264] *See, e.g.*, FED. TRADE COMM'N, TO PROMOTE INNOVATION: THE PROPER BALANCE OF COMPETITION AND PATENT LAW AND POLICY, ch. 3, at 43 (Oct. 2003) ("Testimony regarding the role of patents [in the computer hardware and semiconductor sectors] was mixed."); *Id.* at ch. 3, at 56 ("Many panelists and participants expressed the view that software and Internet patents are impeding innovation."); Roin, *supra* note 14, at 679–80.

[265] Elon Musk, *All Our Patent Are Belong to You*, TESLA BLOG (June 12, 2014), http://www.teslamotors.com/blog/all-our-patent-are-belong-you.

[266] *Ford Opens Portfolio of Patented Technologies to Competitors To Accelerate Industry-Wide Electrified Vehicle Development*, FORD (May 28, 2015), https://media.ford.com/content/fordmedia/fna/us/en/news/2015/05/28/ford-opens-portfolio-of-patented-technologies-to-competitors-to-.html.

States inventors.[267] As a corollary, therefore, any decrease in the value of United States patents will actually tend to affect foreign inventors more than United States inventors.[268]

Moreover, analyses of global competitiveness must account for the fact that strong patents reduce domestic rivalry among United States companies. In a separate article, Professor Hubbard demonstrates that United States policymakers have failed to account for the patent system's reduction in domestic rivalry.[269] United States patents insulate United States companies from domestic competition, but intense domestic rivalry tends to increase a country's global competitiveness.[270] In essence, domestic rivalry acts as a sort of training ground that prepares business for global competition. Thus, weakening United States patents will increase domestic rivalry among United States businesses, which will support an increase in global competitiveness. Hubbard urges policymakers to weigh those competitive gains against any changes in incentive to innovate caused by weakening patents.[271]

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[267] William Hubbard, *Competitive Patent Law*, 65 FLA. L. REV. 341, 371–73 (2013). As Professor Hubbard notes, patents are only a proxy for innovation, and thus United States businesses might enjoy disproportionate effects of stronger patents if the United States patents obtained by United States inventors are more commercially valuable. *Id.* at 373 n.220.

[268] Hubbard's observations also counsel for further research on the United States' inventive profile compared to other countries. Specifically, suppose that the bulk of United States inventive activity is in industries that do not benefit much from, or are harmed by, the patent system, whereas the major competitors' inventive activity is in industries that need stronger patent protection. If this were true, then weakening patents across the board would disproportionately benefit the United States as compared to its inventive rivals. *Id.* at 375–78 (analyzing ways to selectively strengthen United States patents in a way that disproportionately affects United States businesses). To study this, future researchers would need to look not simply at the number of patents in each technology sector, but also the value of those patents.

[269] William Hubbard, *The Competitive Advantage of Weak Patents*, 54 B.C. L. REV. 1909, 1912–13 (2013).

[270] *Id.* at 1936–38, 1942–44.

[271] *Id.* at 1913.

Hubbard's insights align with intuition and psychological insights.[272] Insulation breeds complacency, and complacent firms are poor competitors when the insulation is removed, as it can be in global competition. His analytical framework has direct application to this Article's proposal to weaken patents and provides an independent variable favoring weakening patents.[273]

Of course, Hubbard's observations used a static model of inventor location; that is, he assumed that inventors, typically businesses, would not relocate to different countries seeking stronger patents or less intense competition.[274] Thus, one must consider the strength of the argument that businesses will leave the United States in response to weaker patents.

This Article recognizes the potential for relocation responses but concludes that they will likely be marginal. For one thing, industries in which the executives are complaining about strong patents are unlikely to leave the United States if patents are weakened. Indeed, the opposite might occur—the United States may see companies relocate to it.

Additionally, many factors contribute to a company's location decisions, including proximity to highly skilled workers, supporting industries, low production and distribution costs, favorable regulatory environments, and the personal desires of the company's leadership.[275] These and other factors are highly dependent on the specific company and industry. It is important to note, however, that regarding highly skilled workers, the United States ranks seventh in the 2014–2015 World Economic

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[272] *See* Bair, *supra* note 1, at 325 (discussing Parkinson's theory of work and complacency).

[273] This is not to say that all effects of any changes would be positive, especially early on. For example, a significant trade surplus for the United States is in the form of intellectual property royalties, and weakening patents would likely reduce this trade surplus. Ernest H. Preeg, *U.S. Trade Surplus in Business Services Peaks Out*, MAPI (Jan. 23, 2014), https://www.mapi.net/research/publications/us-trade-surplus-business-services-peaks-out (showing, at Table 5, a 2012 United States trade surplus in intellectual property of $82,000,000,000). The reduction should be offset by competitiveness gains.

[274] In his *Competitive Patent Law* article, Professor Hubbard was considering ways to strengthen, not weaken, United States patents in ways that benefited the United States. *See* Hubbard, *supra* note 267, at 341–42. Thus, any movement of businesses would have tended to be into the United States.

[275] *See, e.g.*, Michael E. Porter, *The Competitive Advantage of Nations*, 90 HARV. BUS. REV., Mar.–Apr. 1990, at 77–79, 82–83 (indicating that high skilled labor is important for competitive advantage and discussing supporting industries).

Forum's ranking for Higher Education and Training.[276] In addition, the United States ranks seventh in the most recent World Bank "ease of doing business" ranking, suggesting a favorable regulatory environment.[277] Finally, regarding a company's location, the United States is a particularly fertile ground for startups, suggesting that many new, innovative companies will begin in the United States.[278]

Furthermore, even if lawmakers weaken patents, companies will continue to locate in the United States because it represents the world's top consumer market.[279] Many companies will need offices in the United States to serve this large consumer market adequately and thus are unlikely to flee en masse. Even if foreign countries with stronger patent systems become more enticing for rent-seeking firms, companies can retain offices in the United States while continuing to take advantage of other countries' patent laws.

Because this Article advocates for weakening but not abolishing patents, the United States market would continue to provide opportunities for patent-boosted pricing under this Article's approach. The patent system would thus continue incentivizing companies to maintain a presence in the United States, even assuming the net effects of the proposed changes are negative for certain companies.

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[276] WORLD ECON. FORUM, GLOBAL COMPETITIVENESS REPORT 2014–2015, at 19 (Klaus Schwab ed., 2014).

[277] *Ease of Doing Business Index*, WORLD BANK, http://data.worldbank.org/indicator/IC.BUS.EASE.XQ?order=wbapi_data_value_2014+wbapi_data_value+wbapi_data_value-last&sort=asc (last visited Apr. 2, 2016).

[278] Rip Empson, *Startup Genome Ranks the World's Top Startup Ecosystems: Silicon Valley, Tel Aviv & L.A. Lead the Way*, TECHCRUNCH (Nov. 20, 2012), http://techcrunch.com/2012/11/20/startup-genome-ranks-the-worlds-top-startup-ecosystems-silicon-valley-tel-aviv-l-a-lead-the-way/ (noting that five of the top six cities in a recent ranking of top cities for startups were in the United States). Of course, the strength of the current patent system may be a contributor to this state of affairs.

[279] Toperz Team, *World Top Consumer Markets Ranking*, 1RESERVOIR (Mar. 5, 2013), http://www.1reservoir.com/awow-8788.

4. Additional Considerations

Besides the three highly important points of attention discussed above, policymakers will need to weigh numerous other considerations. For example, weakening the patent system will, all else equal, tend to cause patentable inventions to occur at a later time, which will make the inventions fall into the public domain later.[280] In addition, where possible, companies may turn to trade secrecy to protect innovations that they perceive the patent system will inadequately protect. Moreover, policymakers should consider whether alternative forms of protection could prevent free-riding; these include digital rights management, copyrights, trademarks, trade secrecy, and design patents. To the extent that one or more of these protections is available more often in today's technological environment than in the past, they will soften some effects of a weaker patent system.

B. Method of Change to the Patent System

Having concluded that policymakers should weaken patents by at least twenty-five to fifty percent, this Article now turns to the method by which such weakening should take place. One way to weaken patents is to enact uniform—that is, technology-neutral—changes that apply equally to all patents.[281] Though there are many choices for such changes, three are explored here. The first Subsection explores shortening the patent term. The second explores increasing maintenance fees. Finally, the third Subsection explores a variety of doctrinal changes that, while facially neutral, clearly target certain technologies.

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[280] *See* Duffy, *supra* note 231.

[281] Beyond uniform changes, policymakers can also alter the law in ways that explicitly target specific technologies. For example, lawmakers could simply declare that software patents are not patentable. *See* Leahy–Smith America Invents Act, Pub. L. No. 112–29, § 14, 125 Stat. 284 (2011) (excluding tax strategies from patent protection). Line-drawing problems, strategic behavior to avoid such reforms, and the changing nature of technology make facially targeted reforms less attractive. *See, e.g.*, Julie E. Cohen & Mark A. Lemley, *Patent Scope and Innovation in the Software Industry*, 89 CALIF. L. REV. 1, 8–14 (2001) (noting line-drawing problems and efforts to avoid lines by patentees); Roin, *supra* note 14, at 710–11.

1. Shortening the Patent Term

Recall that the current patent system is primarily a one-size-fits-all framework. That is, patents covering cutting-edge pharmaceuticals, novel microchip technology, and simple supposed inventions like methods for filming yoga classes[282] all generally receive the same twenty-year term[283] and impart the same legal rights. Despite the theoretical benefits of tailoring patent terms to the benefits and costs of individual inventions, the complexities of obtaining data for and administering such a system have stymied tailored reforms.[284] Weakening patents through uniform changes to patent laws can avoid many of the difficulties of tailored reform.[285]

By weakening patents by twenty-five to fifty percent, lawmakers could shorten their useful life by the same percentages. At first, one might think shortening a patent from twenty years to ten years would weaken it by half, but this ignores the time it takes to examine a patent. The current patent term is twenty years from the date of filing.[286] However, after a patent is filed, the United States Patent and Trademark Office ("Patent Office") examines it, and on average, a patent will take about three years before it issues.[287] Thus, the average life

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[282] Method and Apparatus for Yoga Class Imaging and Streaming, U.S. Patent No. 8,605,152 B2 (filed Feb. 8, 2013).

[283] This Article recognizes that maintenance fee requirements establish a de facto differentiation in patent term and it is discussed below in Part III.B.2. The twenty-year term is granted in 35 U.S.C. § 154(a)(2) (West 2014). Patent terms can be adjusted for various delays, the most significant of which are extensions for pharmaceuticals based on delays involved in obtaining regulatory approval. *See* 35 U.S.C. § 156 (2012). Other extensions are for delays at the patent office. 35 U.S.C. § 154(b).

[284] *See* Roin, *supra* note 14, at 706–12 (discussing barriers to tailored reforms).

[285] Uniform changes are, in one sense, technology-neutral in that the law applies equally to all patents regardless of technology. *Id.* at 704 (referring to uniform changes as technology-neutral). However, neutrality in application is not the same as neutrality in effect. Uniform changes to patent strength will affect different industries differently because the patent system works differently for different technologies. Arti K. Rai, *Building a Better Innovation System: Combining Facially Neutral Patent Standards with Therapeutics Regulation*, 45 HOUS. L. REV. 1037, 1038–39 (2008) (describing facially neutral judicial changes to patent laws that have a disparate impact on technology sectors).

[286] More accurately, the current patent term starts from its earliest priority date. 35 U.S.C.A. § 154(a)(2).

[287] Dennis Crouch, *Average Pendency of US Patent Applications*, PATENTLY-O (Mar. 20, 2013), http://patentlyo.com/patent/2013/03/average-pendency-of-us-patent-applications.html.

of an issued patent is about seventeen years.[288] This means that to weaken patents by half, lawmakers should divide seventeen by two and add the three years for pendency. The result is that a half-strength patent would last about eleven-and-one-half years from the date of filing.

Shortening the patent term would decrease the expected profits from patents.[289] According to the incentive-to-invent and incentive-to-commercialize theories of patents, the decrease in expected profits would shift expenditures away from R&D, or to different R&D, which in turn would lower the number of innovations, or at least slow the rate at which they were developed. With fewer innovations, the productive capacity of the economy would decrease.

Even according to the incentive theories, however, weakening patents would have some salutary effects. It would decrease duplicative costs involved in the race to innovate. It would also make innovations available for general use by the public sooner, thus allowing those innovations to increase the economy's productive capacity.[290] Further, increasing the technological commons would beneficially increase the rate at which innovations could build on earlier innovations, potentially increasing the rate of innovation.[291]

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[288] Patent owners cannot file infringement suits until the patent issues. *See* 35 U.S.C. § 271(a). Pending patent applications are not worthless, however. Patent owners can obtain a reasonable royalty from an infringer even for periods the patent application was pending if the patent application was published, the infringer had actual notice of the published application, and the invention as claimed in the patent is substantially identical to the invention as claimed in the published patent application. 35 U.S.C.A. § 154(d).

[289] The general effects of lengthening or shortening the patent term have been well understood for decades. *See, e.g.*, Machlup, PATENT SYSTEM, *supra* note 3, at 66–68. A fifty percent decrease in patent term would not necessarily decrease the value of the patent to its owner by half. For example, the useful life of the technology might have been shorter than the twenty-year patent term.

[290] *Id.* Shortening the patent term may, under certain circumstances, cause inventions to fall into the public domain at a later time because the invention would not occur for a longer time. Duffy, *supra* note 231, at 493–96; John F. Duffy, A Minimum Optimal Patent Term 3 (Jan. 9, 2003) (unpublished manuscript), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=354282.

[291] *See, e.g.*, Roin, *supra* note 14, at 694–97.

Balancing these and other benefits and costs is the difficult, if not impossible task of policymakers. Although a substantial body of theoretical literature analyzes the optimal patent term,[292] commentators repeatedly lament the inability to obtain the proper data to analyze the effects of uniform changes to patent laws.[293] This Article's proposal acknowledges the difficulty of obtaining much of the relevant data but propounds that a key factor in the complex equations, the cost of innovation, has greatly lowered in recent years. Like other studies of the patent system, this Article cannot prove this assertion empirically. There is no evidence that any other key variables of the innovation calculus have changed with any magnitude to counteract the decreased cost of innovation.

As discussed, one variable that has changed is the speed and cost at which a copier can copy a new innovation. While this would be an important factor if one were to abolish the patent system, its effects are minimal when the patent system is only weakened between twenty-five and fifty percent. Another important variable, the transaction costs associated with finding and licensing patents, might limit the harms of longer patents on follow-on innovation. If patents were easily identified and licensed to all innovators, follow-on innovation would only be impeded by the costs of those license rates. It is true that the Internet and other technologies have reduced the costs of finding relevant patents and communicating with patent owners. Likewise, standards-setting organizations in some cases reduce licensing costs.[294] However, it does not appear that transaction costs have decreased in any fundamental way.[295]

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[292] *E.g.*, Michael Abramowicz, *Orphan Business Models: Toward a New Form of Intellectual Property*, 124 HARV. L. REV. 1362, 1396 (2011); Khoury, *supra* note 14; Peter S. Menell, *A Method for Reforming the Patent System*, 13 MICH. TELECOMM. & TECH. L. REV. 487, 493 (2007). *See generally* WILLIAM D. NORDHAUS, INVENTION, GROWTH, AND WELFARE: A THEORETICAL TREATMENT OF TECHNOLOGICAL CHANGE (1969); David S. Abrams, *Did TRIPS Spur Innovation? An Analysis of Patent Duration and Incentives To Innovate*, 157 U. PA. L. REV. 1613 (2009); Nancy T. Gallini, *Patent Policy and Costly Imitation*, 23 RAND J. ECON. 52 (1992); Richard Gilbert & Carl Shapiro, *Optimal Patent Length and Breadth*, 21 RAND J. ECON. 106 (1990); Andrew W. Horowitz & Edwin L.-C. Lai, *Patent Length and the Rate of Innovation*, 37 INT'L. ECON. REV. 785 (1996); Eric E. Johnson, *Calibrating Patent Lifetimes*, 22 SANTA CLARA COMPUTER & HIGH TECH. L.J. 269 (2006).

[293] *See, e.g.*, Roin, *supra* note 14, at 704–05.

[294] Jorge L. Contreras, *Fixing FRAND: A Pseudo-Pool Approach to Standards-Based Patent Licensing*, 79 ANTITRUST L.J. 47, 47–53 (2013) (describing potential

It is also important to note that patents can be weakened by changing their breadth[296] and that recent United States Supreme Court decisions appear to have weakened patents to some extent.[297] Further, recent legislative changes to the patent system may weaken patents in some areas of technology. To the extent that court decisions or legislative changes have already weakened patents as a whole, the length by which the patent term should be shortened would decrease. The recent changes, however, are not likely to have a profound impact on the patent system on the level that this Article proposes.[298]

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efficiencies and contemporary problems with standards-developing organization ("SDO") patent licensing); Mark A. Lemley, *Intellectual Property Rights and Standard-Setting Organizations*, 90 CALIF. L. REV. 1889, 1893 (2002).

[295] Contreras, *supra* note 294; *see also* Rebecca S. Eisenberg, *Patent Costs and Unlicensed Use of Patented Inventions*, 78 U. CHI. L. REV. 53, 64–66 (2011) (describing search costs potential infringers must incur to find patents); Merges & Nelson, *supra* note 1, at 874 n.146 (cataloging literature showing the high costs of licensing); Michael Risch, *Licensing Acquired Patents*, 21 GEO. MASON L. REV. 979, 982–89 (2014) (describing stages of patent licensing); Sichelman, *supra* note 8 (reviewing transaction costs that can stifle commercialization).

[296] Gilbert and Shapiro construct an economic model that suggests that, as between length and breadth, changing patent breadth is the better policy lever. Gilbert & Shapiro, *supra* note 292, at 106–11. As the authors of this Article admit, this model ignores the cumulative nature of innovation. *Id.* at 112.

[297] *See infra* note 328 (listing cases).

[298] The main exception to this may be the decision in *Alice Corp. Pty. Ltd. v. CLS Bank International*, 134 S. Ct. 2347 (2014). At the time of this Article, only one Federal Circuit decision has upheld a software patent challenged on patentable subject matter grounds. *See Improved Search LLC v. AOL, Inc.*, Civ. No. 15-262-SLR, 2016 WL 1129213, at *8 & n.4 (D. Del. Mar. 22, 2016). The scope of the decision is unclear, but many believe it significantly weakens software patents. Gene Quinn, *A Software Patent Setback:* Alice v. CLS Bank, IPWATCHDOG (Jan. 9, 2015), http://www.ipwatchdog.com/2015/01/09/a-software-patent-setback-alice-v-cls-bank/id=53460/ ("Based on [the *Alice*] decision it is hard to see how any software patent claims written in method form can survive challenge."); Julie Samuels, *Patent Trolls Are Mortally Wounded*, SLATE (June 20, 2014, 1:47 PM), http://www.slate.com/articles/technology/future_tense/2014/06/alice_v_cls_bank_supreme_court_gets_software_patent_ruling_right.html ("[The decision] significantly tighten[ed] the standard for what is and what is not patentable."). One empirical study shows that courts and the Patent Office are invalidating software patents at a high rate after *Alice*. Jasper L. Tran, *Software Patents: A One-Year Review of* Alice v. CLS Bank, 97 J. PAT. TRADEMARK OFF. SOC'Y 532, 541 (2015) (noting that during the first year after *Alice*, the Federal Circuit invalidated software patents for lacking patentable subject matter at a rate of 94.1%, the Patent Trial and Appeal Board at 90.8%, and the district courts at 69.7%); *see also* Robert R. Sachs, *The One Year Anniversary: The Aftermath of #AliceStorm*, BILSKIBLOG (June 20, 2015), http://www.bilskiblog.com/blog/2015/06/the-one-year-anniversary-the-aftermath-of-alicestorm.html.

Even if it is accepted that policymakers should shorten the patent term, there exists a considerable barrier in the form of the 1994 international Agreement on Trade-Related Aspects of Intellectual Property[299] ("TRIPS"). The TRIPS agreement requires the patent term to be at least twenty years from the filing date.[300] In addition to being politically embarrassing to violate a treaty that the United States pushed for vigorously,[301] any violation of the agreement would allow other countries to complain and possibly institute retaliatory trade measures.[302] Thus, whatever the merits of shortening the patent term, it is widely supposed that doing so is politically impossible at this time.

Even if TRIPS did not represent a major obstacle, the political economy of patent law makes it extremely difficult to push through a change in the patent term. For example, software companies might welcome the change, whereas biotechnology and pharmaceutical companies would fiercely oppose it.[303] Historically, the biopharma industry lobby has prevented major changes to the patent system that might weaken patents.[304] This suggests that shortening the patent term would be an incredibly difficult endeavor unless lawmakers gave a carve-out to the biopharma sector.[305]

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[299] Agreement on Trade-Related Aspects of Intellectual Property Rights, Apr. 15, 1994, Annex 1C, 1869 U.N.T.S. 299 (1994) [*hereinafter* TRIPS].

[300] *Id.* art. 33.

[301] *See* DANIEL GERVAIS, THE TRIPS AGREEMENT: DRAFTING HISTORY AND ANALYSIS 11–27 (4th ed. 2012) (documenting the negotiation history of the TRIPS agreement).

[302] *See* TRIPS, *supra* note 299, art. 64(1); Rachel Brewster, *The Remedy Gap: Institutional Design, Retaliation, and Trade Law Enforcement*, 80 GEO. WASH. L. REV. 102, 112–17 (2011) (outlining the dispute settlement system under TRIPS).

[303] *See* Jay P. Kesan & Andres A. Gallo, *The Political Economy of the Patent System*, 87 N.C. L. REV. 1341, 1352–53, 1358–65 (2009).

[304] *See, e.g.*, Roin, *supra* note 14, at 679–81.

[305] Providing an appropriate carve-out carries its own line drawing and political economy issues. *See* Rai, *supra* note 285, at 1040 (noting that a patent law carve-out for a given industry may be hard to define and apply).

2. Increasing Maintenance Fees

If TRIPS prohibits shortening the patent term, policymakers can likely avoid TRIPS conflicts and achieve a similar effect by increasing patent maintenance fees, also called renewal fees.[306] Several commentators have analyzed maintenance fees, particularly as a deterrent to nonpracticing entities, also called patent trolls.[307] As their name implies, maintenance fees are fees that must be paid to keep a patent in force. Fees must be paid by 3.5, 7.5, and 11.5 years after the patent is granted.[308] If the fees are not paid, the patent will expire.[309] Currently, maintenance fees are $1,600, $3,600, and $7,400, respectively, for the payments required at 3.5, 7.5, and 11.5 years.[310]

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[306] Brian J. Love, *An Empirical Study of Patent Litigation Timing: Could a Patent Term Reduction Decimate Trolls Without Harming Innovators?*, 161 U. PA. L. REV. 1309, 1357 (2013) (discussing an increase in maintenance fees as a deterrent to non-practicing entity patent litigation and assuming that it would avoid trouble with TRIPS).

[307] Colleen V. Chien, *Reforming Software Patents*, 50 HOUS. L. REV. 325, 360–63 (2012) (discussing an increase in maintenance fees as a deterrent to non-practicing entity patent litigation); Francesca Cornelli & Mark Schankerman, *Patent Renewals and R&D Incentives*, 30 RAND J. ECON. 197, 208 (1999) ("[R]enewal fees should rise much more with patent length than existing fee schedules."); Love, *supra* note 306; Gerard N. Magliocca, *Blackberries and Barnyards: Patent Trolls and the Perils of Innovation*, 82 NOTRE DAME L. REV. 1809, 1836–37 (2007) (noting that maintenance fee increases could help battle patent trolls); Kimberly A. Moore, *Worthless Patents*, 20 BERKELEY TECH. L.J. 1521, 1551–52 (2005); David S. Olson, *Removing the Troll from the Thicket: The Case for Enhancing Patent Maintenance Fees in Relation to the Size of a Patent Owner's Non-Practiced Patent Portfolio*, *in* Boston College Law School Legal Studies Research Paper Series (Aug. 30, 2013), *available at* http://ssrn.com/abstract=2318521.

[308] 35 U.S.C. § 41(b) (2012). Paying after the 3.5 years, 7.5 years, and 11.5 years results in the need to pay an additional surcharge. *Id.* § 41(b)(2).

[309] The patentee may be excused for late payment if the tardiness was "unintentional." *Id.* § 41(c). Section 202(b)(1)(B) of The Patent Law Treaties Implementation Act of 2012 amended 35 U.S.C. § 41(c)(1) to delete a twenty-four-month time limit for unintentionally delayed maintenance fee payments and the reference to an "unavoidable" standard for failure to timely pay fees. Patent Law Treaties Implementation Act of 2012, Pub. L. No. 112–211, § 202(b)(1)(B), 126 Stat 1527, 1535–36.

[310] *See USPTO Fee Schedule*, USPTO, http://www.uspto.gov/learning-and-resources/fees-and-payment/uspto-fee-schedule (last revised Apr. 1, 2016). Small and micro entities can get fee reductions. *Id.* The America Invents Act grants the Patent Office power to set its own fees "to recover the aggregate estimated costs to the Patent Office for processing, activities, services, and materials relating to patents." Leahy-Smith America Invents Act, Pub. L. No. 112-29, § 10, 125 Stat. 284, 316–17 (2011). The Patent Office interprets this law to permit it to set, among other fees, maintenance fees. *Fees and Budgetary Issues*, USPTO, http://www.uspto.gov/patent/

Maintenance fees tend to push less valuable inventions into the public domain. If a given patent produces little income and does not promise to do so in the future, the rational economic decision is to not pay the maintenance fee. Indeed, studies show that about fifty percent of issued patents expire prematurely for failure to pay maintenance fees.[311]

To weaken patents by twenty-five to fifty percent, the Patent Office could raise some maintenance fees substantially or increase the frequency with which they are required, or both.[312] This method of change allows more flexibility compared to shortening the patent term. For example, the Patent Office could raise only the 11.5-year maintenance fee, it could raise all of them, or it could increase the frequency to institute a yearly fee after a specific time. Note that the fees are measured not from the time of patent filing, but from patent issuance. Because the average patent pendency is about three years, maintenance fees on average will be due 6.5, 10.5, and 14.5 years.[313] Thus, for example, to achieve something close to the proposed twenty-five to fifty percent weaker patents, the Patent Office could dramatically raise the 7.5-year or 11.5-year maintenance fee, which, because of patent pendency times and a small additional fee for payments up to six months late, would come due at the eleventh year and fifteenth year after issuance, respectively.

One concern with raising maintenance fees is not to do it so early that the patentee might not have enough time to ascertain the invention's commercial potential. The suggestion not to begin raising fees until at least the second fee term alleviates this concern. So, for example, an aggressive fee schedule to weaken patents would have the first fee set at $5,000 in year five and then $1,000 multiplied by the number of years thereafter—for example, $10,000 in year ten—ensuring only the commercialized and lucrative patents remained in force.

laws-and-regulations/america-invents-act-aia/fees-and-budgetary-issues (last visited Apr. 2, 2016).

[311] Moore, *supra* note 307, at 1526; Dennis Crouch, *Patent Maintenance Fees*, PATENTLY-O (Sept. 26, 2012), http://patentlyo.com/patent/2012/09/patent-maintenance-fees.html.

[312] There is insufficient data to know what magnitude of increase would mimic a fifty percent reduction in patent term. It might be approximately a ten-fold or one-hundred-fold increase, if not more.

[313] Love, *supra* note 306, at 1318 n.41.

Another concern with raising maintenance fees is that high fees will disproportionately crowd out individual inventors and small businesses. The Patent Office addresses similar concerns by offering fifty percent fee reductions for "small" entities—generally universities, nonprofits, and businesses with fewer than 500 employees[314]—and seventy-five percent fee reductions for "micro" entities—generally individuals who have not filed more than four other patent applications and have an income of less than or equal to three times the median household income.[315] This Article proposes to maintain reduced fees for small and micro entities.

Although significantly increasing maintenance fees will have similar impacts to reducing the patent term, political opposition to this approach from the biopharma sector is expected to be less intense compared to shortening the patent term. This prediction is based on the realities of invention and commercial success in biopharma. Specifically, an "overwhelming number of drugs that enter clinical trials [do not] actually get approved by the FDA, so drugmakers try to recover those costs when they have a successful product."[316] In other words, companies identify new drug candidates early in the development process and must patent them before they know if they will actually work in humans.[317] Ten years after filing for the patent, however, the company will generally know whether the drug will be approved for use in humans and will thus be able to identify the one very valuable patent among the thousands of valueless patents.

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[314] *See* 37 C.F.R. § 1.27 (2015); 13 C.F.R. § 121.802 (2015).

[315] 35 U.S.C. § 123 (West 2014).

[316] Jason Millman, *Does It Really Cost $2.6 Billion To Develop a New Drug?*, WASH. POST (Nov. 18, 2014), http://www.washingtonpost.com/blogs/wonkblog/wp/2014/11/18/does-it-really-cost-2-6-billion-to-develop-a-new-drug/.

[317] Sarah E. Eurek, Note, *Hatch–Waxman Reform and Accelerated Market Entry of Generic Drugs: Is Faster Necessarily Better?*, 2003 DUKE L. & TECH. REV. 18, 20 (2003) ("This high cost is mostly due to the fact that for every 5,000 chemicals tested in animals, only five go on to human clinical testing, and of this five, only one makes it to market.").

Thus, biopharma companies are less likely to object to a system that increases late-stage maintenance fees because, by that point, they will know whether their patents are valuable or not.[318] When a biopharma patent is valuable, it is generally very valuable, such that a high maintenance fee will be a drop in the bucket compared to the drug's value.[319] Empirical research supports this analysis.[320]

Raising maintenance fees would likely have other beneficial effects. Most obviously, it would increase the commons—the technology in the public domain.[321] Further, economic research suggests it could increase social welfare.[322] Perhaps most importantly, it would tend to lessen the problem of nonpracticing entities by significantly raising their operating costs, especially since nonpracticing entities tend to assert patents that are coming to the end of the twenty-year term.[323] Finally, raising renewal fees would help clear patent thickets—collections of patents that impede follow-on innovation—and defensive patents—patents held not to assert against others, but as a disincentive to others against suing the defensive patent holder.[324] David Olson chronicles the problems with patent thickets in detail and recommends using maintenance fees to alleviate the problem.[325]

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[318] *Cf.* Olson, *supra* note 307, at 37 (noting that biopharma companies tend to have smaller patent portfolios).

[319] James Bessen & Michael J. Meurer, *Lessons for Patent Policy from Empirical Research on Patent Litigation*, 9 LEWIS & CLARK L. REV. 1, 10 (2005) ("[Pharmaceutical f]irms get patents at an early stage of commercialization, get no value out of most patents, and get a bonanza from a few.").

[320] Moore, *supra* note 307, at 1543–44, 1547–48.

[321] Admittedly, only less commercially valuable inventions would expire.

[322] Cornelli & Schankerman, *supra* note 307, at 197 (finding that raising maintenance fees more sharply for high R&D productivity firms would yield significant welfare gains).

[323] Chien, *supra* note 307 (discussing an increase in maintenance fees as a deterrent to non-practicing entity patent litigation); Love, *supra* note 306, at 1312 ("NPEs, on the other hand, begin asserting their patents relatively late in the patent term and frequently continue to litigate their patents to expiration."); *id.* at 1357–58 (recommending increasing later-stage maintenance fees); Magliocca, *supra* note 307, at 1836–37 (noting that maintenance fee increases could help battle patent trolls); Olson, *supra* note 307, at 2–10.

[324] Olson, *supra* note 307, at 5–7.

[325] *Id.* at 2–10, 22–30.

Raising later-stage maintenance fees thus represents a promising proposal, but it must be approached with caution. Maintenance fees are a big revenue generator for the Patent Office, at times constituting more than one-half of Patent Office revenues.[326] Changes in maintenance fees must be done with an eye toward the Patent Office's overall revenue, and it will likely be necessary to change other fees to make up for differences in renewal fee income.

Further, maintenance fee changes must be made in contemplation of the Patent Office's desire to act in a self-interested manner. Intuition suggests that the Patent Office will have a temptation to act in a way to maximize its revenue, and empirical research supports this proposition.[327] Under this Article's proposal, the Patent Office may be averse to increasing later stage maintenance fees if it will decrease its revenue.

Even if the Patent Office is willing to change its fees according to this proposal, the public should be aware of incentives that might result. On the one hand, the Patent Office might desire to issue too many broad—and thus valuable—patents to ensure that a substantial number of patents will be worth paying high maintenance fees. On the other hand, perhaps the Patent Office will be tempted to issue many more patents of relatively small value, ensuring a large number of early-stage maintenance fees. It is possible that these two temptations will offset each other, resulting in a more socially optimal patent issuance rate.

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[326] Dennis Crouch, *USPTO Maintenance Fees*, PATENTLY-O (Feb. 20, 2012), http://patentlyo.com/patent/2012/02/uspto-maintenance-fees.html ("Over half of the USPTO operational budget is derived from maintenance (or renewal) fees paid by patentees.").

[327] Michael D. Frakes & Melissa F. Wasserman, *Does Agency Funding Affect Decisionmaking?: An Empirical Assessment of the PTO's Granting Patterns*, 66 VAND. L. REV. 67, 69 (2013) (noting that the Patent Office, because it is funded largely by postfiling fees, will be tempted to grant more patents in an effort to ensure a continued stream of funding); Michael D. Frakes & Melissa F. Wasserman, *The Failed Promise of User Fees: Empirical Evidence from the U.S. Patent and Trademark Office*, 11 J. EMPIRICAL LEGAL STUD. 602, 609 (2014) (noting that the Patent Office, because it is funded largely by postfiling fees, will be tempted to extend preferential examination treatment to simple technologies that are inexpensive to process).

3. Semiselective Changes to Patent Strength

Besides the broad-reaching reforms to patent terms and maintenance fees described above, lawmakers could instead manipulate various patent law doctrines in ways that would target specific technologies. Indeed, courts already seem to be doing this, especially for software patents and some medical-related inventions.[328] As discussed previously, many believe that the Supreme Court's decision in *Alice Corp. Pty. Ltd. v. CLS Bank International*[329] weakens software patents significantly.[330]

Extending such semitargeted approaches to other technologies could decrease the incentives to innovate in line with this Article's recommendation. The way forward, however, is complex. For example, how should lawmakers change patent law to target products whose innovation costs are most affected by 3D printing? 3D printers themselves and materials used as 3D printing "inks" are not the products whose innovation costs are most affected by 3D printing. Rather, 3D printable objects will enjoy the lowered innovation costs. Developers can digitize these products in CAD programs, then share and manipulate them in digital form.

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[328] For further analysis regarding software patents, see Nautilus, Inc. v. Biosig Instruments, Inc., 134 S. Ct. 2120, 2124 (2014) (raising the standard for definiteness in patent claims); Alice Corp. Pty. Ltd. v. CLS Bank Int'l, 134 S. Ct. 2347, 2358 (2014) (arguably raising the standard for patentable subject matter). For more information on medical-related patents, see Ass'n for Molecular Pathology v. Myriad Genetics, Inc., 133 S. Ct. 2107, 2116 (2013) (arguably raising the standard for patentable subject matter); Mayo Collaborative Servs. v. Prometheus Labs., Inc., 132 S. Ct. 1289, 1294 (2012) (arguably raising the standard for patentable subject matter). In addition, recent court decisions have weakened patents generally but do not appear directed at particular technologies. *See, e.g.*, KSR Int'l Co. v. Teleflex Inc., 550 U.S. 398, 417–18 (2007) (making more would-be inventions obvious); eBay Inc. v. MercExchange, L.L.C., 547 U.S. 388, 391–92 (2006) (making it more difficult for patent owners to obtain an injunction). The *eBay* decision was likely motivated by a desire to weaken patent trolls.

[329] 134 S. Ct. 2347.

[330] *See supra* note 298 and accompanying text.

Therefore, by weakening incentives for technologies affected by 3D printing, patent law could refuse to protect CAD files, even if the CAD file would print an object that was patented.[331] If patents do not protect CAD files, individuals would be free to create, share, and even perhaps sell CAD files that would print the patented physical devices.[332] In such a world, a patent holder would often have a difficult time enforcing a patent because it would be difficult to identify who actually infringed by printing the CAD file.

It may be that *Alice* will preclude patent protection for CAD files.[333] Even if so, however, patents would continue to be important to 3D printable gods because printing the physical device would constitute infringement as a "making" of the patented invention.[334] Thus, individuals and businesses that print the items could face liability.[335] True, it would be difficult in some cases for the patent owner to detect infringement, such as where an individual prints in the privacy of a home or business for individualized use.[336] The fact of infringement, however, will deter use of the invention because people may want to obey the law or may fear being caught. The fact that the invention is patented will also deter adoption by those who would mass produce the item, as they would be easier to identify.

As a more radical change, lawmakers or courts could take an additional step and seek to eliminate patents in certain technological sectors, such as objects capable of being 3D printed. They could achieve this by reading *Alice* broadly such that inventions capable of being 3D printed represent nothing more than abstract ideas. This would be an extremely broad reading of *Alice*, but at least one court has read the decision in a similar manner.[337] In the end, the patentable subject matter doctrine is

[331] *See* Timothy R. Holbrook & Lucas S. Osborn, *Digital Patent Infringement in an Era of 3D Printing*, 48 U.C. DAVIS L. REV. 1319, 1367 (2014).

[332] *Id.* at 1331.

[333] *Id.* at 1378–79. *But see* Daniel Harris Brean, *Patenting Physibles: A Fresh Perspective for Claiming 3D-Printable Products*, 55 SANTA CLARA L. REV. 837, 854–55 (2015) (arguing that CAD files can be patented).

[334] 35 U.S.C. § 271(a) (2012); Holbrook & Osborn, *supra* note 331.

[335] Holbrook & Osborn, *supra* note 331.

[336] Moreover, owners of the patents to the physical device could bring claims for inducing infringement and contributory infringement. Brean, *supra* note 333, at 840–41.

[337] *See* Thales Visionix, Inc. v. United States, 122 Fed. Cl. 245, 257 (Fed. Cl. 2015) (finding a patent claim ineligible directed to two physical sensors that

a poor tool to use to exclude patents on 3D-printable objects, precisely because any such inventions are tangible and not abstract.

The obviousness doctrine represents another patent doctrine that courts and the Patent Office could enlist to weaken patents on 3D-printable objects. Courts could routinely find 3D-printable inventions to be obvious by reasoning that it is easy to combine prior art components from diverse technology fields when 3D printing is involved. One could also argue that 3D printing technology makes many more inventions "obvious to try."

Although doctrinal tweaks to patent laws do not necessarily weaken patents as much as this Article recommends, they are not without benefits. Most importantly, they are narrowly tailored to specific technology sectors. Narrow tailoring is important because, as discussed in Parts I and II, different disruptive technologies are progressing at different rates. Thus, reforms could target 3D printing related areas now and synthetic biology related areas later when that technology matures. Another potential benefit of doctrinal reform is that the courts, as opposed to Congress, can accomplish it, thus bypassing the interest group wrangling that has stymied other reforms.[338]

In sum, doctrinal avenues have the potential to be more targeted but less stringent than changes to the patent term or maintenance fees. A drawback is that they involve uncertainty in application. The boundaries of both patentable subject matter and obviousness are notoriously unclear, which would lead to unpredictability for users of 3D printing technology. Because doctrinal changes involve too much uncertainty, this Article considers them a second-best option, albeit a good one.

CONCLUSION

This Article has demonstrated a confluence of technological change and several strands of innovation scholarship that join together to commend a weaker patent system. New and emerging technologies dramatically reduce the costs of innovation and will continue to reduce it further. Moreover,

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communicate with an element that will calculate the orientation of an object relative to a moving frame of reference).

[338] Some may understandably argue that bypassing democratic debate is not a benefit. "Benefit" is used narrowly here to mean that doctrinal tweaks accomplish this Article's proposed goal.

mounting critiques of the inventive theories of patent law, scholarship applying psychological and sociological insights to patent law, and research into global competitiveness all join together to present a strong case for weakening patent rights.