A Case for Weaker Patents

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ABSTRACT

This Article provocatively asserts that lawmakers should weaken patents significantly—by between 25% and 50%. The primary impetus for this conclusion is the underappreciated effects of new and emerging technologies, including three-dimensional printing, synthetic biology, and cloud computing. These and other technologies are rapidly decreasing the costs of each stage of the innovation cycle: from basic research, through inventing and prototyping, to marketing and distribution. The primary economic theories supporting patent law hold that inventors and innovators need patents to recoup the costs associated with research, inventing, and commercializing. Because new technologies have begun—and will continue—to dramatically decrease these costs, the case for weakening patents is ripe for analysis.

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CONTENTS

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 compared to the firm who must fight hard to continually out-innovate its competitors.[1] Yet the patent system arose in large part to address an apparent flaw in this line of thinking. Namely, because 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 R&D costs.[2] The patent system purports to provide innovators with the incentive to invent and disclose

[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 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, *Justifying (and Improving) The Patent System: A Behavioral Analysis of Patent Theories*, 1, 30 (draft on file with author) (applying Parkinson's law, which states that work expands to fill the time allotted for it, to patent law to show that a 20-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, 183 (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").

those inventions by granting them a 20-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 recognized 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 post-invention innovation expenditures by strengthening patents—such as by lengthening patent terms or broadening patent coverage.

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 invention to be sold 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]

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[3] *E.g.*, SUBCOMM. ON PATENTS, TRADEMARKS, AND COPYRIGHTS OF S. COMM. ON THE JUDICIARY, 85TH CONG., AN ECONOMIC REVIEW OF THE PATENT SYSTEM (Comm. Print 1958) (prepared by 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 non-economic 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 (1988). Given the utilitarian focus of the U.S. Constitution these theories command less attention. We briefly discuss the labor-desert theory in Part III.

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

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

[7] *Id*. 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

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 will be the cumulative research advances that build upon it.

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 encouraging more complacency.[12]

A perfect world would minimize the patent system's costs by matching exactly the incentive granted for each innovation to the size of the R&D costs for that innovation, also 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,

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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 (noting that "broad 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 (1994).

[11] *See* 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. *See id*. at 369, 384-85; Merges & Nelson, *supra* note 1, at 874 (noting the steep costs accompanying technology licensing).

[12] Merges & Nelson, *supra* note 1, at 872 (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 Notes*, 3M, http://www.post-it.com/wps/portal/3M/en_US/PostItNA/Home/Support/About/ (last

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 a robust literature set analyzing it,[14] the patent system is largely a one-size-fits-all endeavor. The reasons 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]

And no one seems happy with the patent system. A survey of literature examining the patent system demonstrates a pervasive 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 we simply do not know the absolute values of the patent system's costs and benefits.[17] Although we do not know the exact costs and benefits of patents, scholars have carried

visited Feb 26, 2015). 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] *See, 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 (2006); Amir H. Khoury, *Differential Patent Terms and the Commercial Capacity of Innovation*, TEX. INTELL. PROP. L.J. 373 (2010); Benjamin N. Roin, *The Case for Tailoring Patent Awards Based on Time-to-Market*, 61 U.C.L.A. L. REV. 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 198, 203-04 (2004) (expressing concerns against tailoring patents); NAT'L RESEARCH COUNCIL, NAT'L ACADS. SCI., A PATENT SYSTEM FOR THE 21ST CENTURY 41 (Stephen A. Merrill, Richard C. Levin & Mark B. Myers eds., 2004) (assuming that the patent system should remain unitary).

[16] *See, e.g.*, MICHELE BOLDRIN & DAVID K. LEVINE: AGAINST INTELLECTUAL PROPERTY (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] *See, e.g.*, 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. *See* 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.").

on a long tradition of debating whether we should strengthen or weaken the patent system.[18] Some even advocate abolishing the patent system.[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 (collectively, "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 innovation costs have decreased, and will continue to decrease significantly, the relative need for the patent system has, and will continue to, decrease. Thus, this Article argues that patents should be weakened significantly—somewhere between 25% to 50%.

To back up this radical claim, we take an interdisciplinary approach out of appreciation for the fact that innovation spans many disciplines[20]: 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. Together we offer the first thorough catalog of new and emerging technologies and their effects, both general and specific, on innovation costs and the patent system.[21]

We are not alone in recognizing the profound affect new technologies are having on the intellectual property system.[22] In his

[18] *See, e.g.*, THE 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 that 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 (2008) (stating that "effectively abolishing intellectual property protection is the only socially responsible thing to do"); JAFFE & LERNER, *supra* note 15, at 35.

[20] Jan Fagerberg, *Innovation: A Guide to the Literature*, *in* 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.").

[21] Our analysis is thorough, but by nature of space constraints cannot be exhaustive. Our analysis invites additional research from patent experts, technology specialists, and empiricists, among others.

[22] Various commentators have discussed how 3D printing will impact the law, but have not recommended significantly weakening patents. *See, e.g.*, Deven R. Desai, *The*

article *IP in a World Without Scarcity*, professor Mark Lemely looks into the future and sees a world "that promises to end scarcity as we know it for a variety of goods."[23] The thrust of Professor Lemley's article is in line with ours—we agree that one day intellectual property protection will be the exception, not the rule. But unlike Professor Lemley, who focuses on that future and finds it "hard to [make] immediate policy prescriptions", we focus on the present and make detailed suggestions for this transitional period between the status quo and the end of scarcity.

In Part I, this Article introduces the new and emerging technologies, including the Internet,[24] cloud computing, three-dimensional (3D) printing,[25] and synthetic biology, that 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. We explore both the magnitude of the change and the method by which that change should be accomplished. We recommend that lawmakers weaken patents by 25%-50%. 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 we explore shortening the patent term, but realize this

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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 Digitzation 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 (2013) (discussing the possible impact of 3D printing on the future of products liability law); Lucas S. Osborn, *Intellectual Property's Digital Future*, *in* RESEARCH HANDBOOK ON DIGITAL TRANSFORMATIONS (F. Xavier Olleros & Majlinda Zhegu eds., forthcoming 2016); Lucas S. Osborn, *Regulating Three-Dimensional Printing: The Converging Worlds of Bits and Atoms*, 51 SAN DIEGO L. REV. 553, 582-92 (2014); Lucas S. Osborn, *Of PhDs, Pirates, and the Public: Three-Dimensional Printing Technology and the Arts*, 1 TEX. A&M L. REV. 811 (2014).

[23] Mark A. Lemley, *IP in a World Without Scarcity*, __ N.Y.U. L. REV. ___ (forthcoming 2015).

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

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

would be politically difficult. Thus, we recommend dramatically raising patent maintenance (renewal) fees for the end portion of patents lives. Finally, we also explore doctrinal changes that could accomplish some of the same goals as raising maintenance fees, but 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 impact profoundly the innovation cycle for many goods.

A. Three-Dimensional Printing

3D printing, or additive manufacturing, essentially produces a part layer-by-layer. A computer-generated model of the part is sliced and converted into controls for the printer, similar to a computer converting a word document into computer code for a 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 30 years 3D printing has been invented, developed by major corporations, and eventually brought to the average consumer. Following early research Charles Hull is credited with inventing 3D printing in 1983.[26] He invented a stereolithography process and established the first commercial 3D printing company, 3D Systems.[27] Following this, the 1980's were marked by massive amounts of research related to additive manufacturing.

The 1990's saw continued growth and development.[28] Advances included the debut and commercialization of several 3D printing methods,

[26] TERRY WOHLERS & TIM GORNET, 2014 WOHLERS REP. 27-28.
[27] *30 Years of Innovation: The Journey of a Lifetime*, 3D SYSTEMS, (Sep. 17, 2013, 12:09 AM), http://www.3dsystems.com/30-years-innovation.
[28] WOHLERS & GORNET, *supra* note 26, at 1-3.

including fused filament fabrication, selective laser sintering, and material jetting (discussed below). Many industries began using stereolithography, such as the custom biomedical implant industry[29] and the jewelry industry.[30] Due to printing costs the technology was limited to large corporations and specialized industries. In the 2000's the technology continued to advance. Since 2010, 3D printing milestones include a printed car,[31] aircraft,[32] and liver tissue and artificial tissue containing blood vessels.[33]

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-<u>rep</u>licating <u>rap</u>id-prototyper.[34] In 2007 the project's first iteration, the Darwin, was released, spawning a marked change in development of 3D printing technology. The RepRap development community is made of hundreds of developers all over the world sharing designs.

In 2009, a key patent[35] covering the basics of fused filament fabrication expired, opening doors for many small and medium enterprises to develop and sell their own 3D printers. The result was that "everything

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

[30] WOHLERS & GORNET, *supra* note 26, at 2.

[31] 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/.

[32] Clay Dillow, *UK Engineers Print and Fly the World's First Working 3-D Printed Aircraft*, POPULAR SCIENCE (Jul. 28, 2011, 12:44 PM), http://www.popsci.com/technology/article/2011-07/uk-engineers-print-and-fly-worlds-first-working-3-d-printed-aircraft.

[33] David B. Kolesky et al., *3D Bioprinting of Vascularized, Heterogeneous Cell-Laden Tissue Constructs*, 26 ADVANCED MATERIALS 3124 (2014); Andy Coghlan, *3D Printer Makes Tiniest Human Liver Ever*, NEWSCIENTIST (Apr. 23, 2013, 5:10 PM), 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/.

[34] Rhys Jones et al., *RepRap—The Replicating Rapid Prototyper*, 29 ROBOTICA 177, 177-78 (2011).

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

exploded"[36] and now hundreds of small businesses operating in communities like Makexyz and larger companies (such as Shapeways, Ponoko, i.Materialise) are bringing 3D printing to the average consumer by offering 3D printing services online and selling inexpensive 3D printers directly to consumers.[37]

Intriguingly, many of the early patents that cover basic 3D printing technology, including laser sintering (described below), have or will soon expire.[38] 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 further develop this technology.[39] 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, we describe several key methods. For instance, laser-based additive manufacturing uses a laser to selectively melt, sinter, or clad metals, ceramics, or polymers.[40] Laser sintering is often accompanied by subsequent heat and/or pressure treatments to homogenize the material and remove any inherent porosity. Laser cladding deposits material onto a substrate, either to add a coating or to build a new part.[41] Cladding can also repair defective or damaged parts. Parts produced via laser-based additive manufacturing typically have excellent dimensional control. But the use of hot lasers slows the build speed, and the requisite specialized gaseous atmospheres increase the price.

Fused filament fabrication (or fused deposition modeling) extrudes polymeric materials through a hot nozzle onto a stage in a laminar fashion.[42] This method can print in a wide range of thermoplastic

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

[37] WOHLERS & GORNET, *supra* note 26, at 13-14

[38] John Hornick & Dan Roland, *Many 3D Printing Patents Are Expiring Soon*, 3DP INDUSTRY (Dec 29, 2013), http://3dprintingindustry.com/2013/12/29/many-3d-printing-patents-expiring-soon-heres-round-overview/ (listing expiring patents).

[39] *See*, *e.g.*, Mims, *supra* note 36.

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

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

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

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.[43] 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.

Researchers have extending the process of welding to 3D printing.[44] 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 via an electric arc that forms between the welding gun and a metallic print substrate. The use of shield gas, such as argon with aluminum welding, is necessary during printing to prevent the formation of detrimental oxide layers. Gas metal arc welding,[45] gas tungsten arc welding, electron beam melting,[46] electron beam freeform fabrication, and micro-welding[47] are all weld-based additive manufacturing techniques commonly utilized. The weld-based additive manufacturing techniques are typically inexpensive and produce metallic parts without porosity and good interlayer adhesion. 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, the first commercialized form of 3D printing, utilizes ultraviolet light to cure portions of a photopolymer vat one layer at a time.[48] While 3D printing via stereolithography is generally a slow and expensive process, the parts produced by this method exhibit excellent

[43] *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.

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

[45] 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 (2011).

[46] Santos, *supra* note 40.

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

[48] Pham & Gault, *supra* note 42, at 1259.

resolution and dimensional control. Famously, Align Technology for sues stereolithography to make Invisalign clear dental braces.[49]

Material jetting directly deposits droplets of material onto a printing substrate, similar to inkjet printing.[50] Alternatively, droplets of glues or other fixatives are deposited onto a bed of particles, and, in some cases, the glues or fixatives are removed via subsequent chemical or heat treatments. Research has begun extending this technology to the printing of biological tissue.[51] This method of 3D printing can be expensive and limited in regard to mechanical integrity but 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.[52] 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, this technology could likely be implemented by large corporations 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, re-wired molecules could be built in a lab to produce fuel for much less. We might even be able to engineer molecules to solve some of our toughest issues such cleaning up hazardous waste and cleaning inside active systems and pipes. This could all be made possible

[49] Press Release, Align Tech., Inc., Align Technology is Awarded for Excellence in Medical Design and Manufacturing (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.

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

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

[52] Sreenathbabu Akula & K.P. Karunakaran, *Hybrid Adaptive Layer Manufacturing: An Intelligent Art of Direct Metal Rapid Tooling Process*, 22 ROBOTICS & COMPUTER-INTEGRATED MANUFACTURING 113 (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 & MANUFACTURING 1057 (2005).

through the use of synthetic biology. Synthetic biology uses the building blocks of life at the sub-DNA level to re-design 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 re-wired by scientists to target and destroy colon infection and cancer.[53] Building microbials and chemicals from basic building blocks allow researchers to produce synthetic anti-malarial medicines in a cost-effective manner.[54] The efficient production of biofuels from biomass is yet another promising result of synthetic biology research.[55]

The ability to 3D print synthetic biology could make it even easier to develop synthetic organisms and to bring them to commercial production. In synthetic biology it can be very difficult situate all of the nuts and cogs of life into the correct position with the requisite accuracy and resolution. Using a new 3D printing technique known as microcontact printing could simplify this process. Microcontact printing utilizes a polymeric stamp that is coated with the molecules of interest (proteins, antibodies, DNA, etc.).[56] This stamp is pressed against a clean substrate to apply a monolayer of molecules. Researchers have already demonstrated 3D printing arrays of protein and DNA molecules using this new method.[57] Utilizing the computer programs and databases related to synthetic biology that are currently under development,[58] it may not be long until researchers have the ability to design a molecule on a computer and directly 3D print it.

[53] Warren C. Ruder et al., *Synthetic Biology Moving to the Clinic*, 333 SCIENCE 1248 (2011).

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

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

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

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

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

C. Cloud Computing

Another disruptive technology, cloud computing, is changing the landscape of computing at both the personal and commercial level.[59] The average person interfaces with programs that use cloud computing in some form or fashion on a daily basis. For instance, Google's email service Gmail, Google documents, Facebook, and Twitter all used cloud-based technology.[60] 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.[61]

Cloud computing is a centralized form of computing in which the average user employs the Internet to accesses programs, files, and services stored on servers at an external, fixed location.[62] It can turn computing and software into a pay-as-you-use utility.[63] 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 she needs for research.[64]

Many entrepreneurs and small businesses have begun utilizing cloud computing as a means to reduce their start-up costs.[65] For their first

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[59] *See* 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.

[60] 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).

[61] Ogunde, *supra* note 60, at 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, 602 (2009).

[62] Buyya, *supra* note 61, at 599; Ogunde, *supra* note 60, at 79.

[63] Buyya, *supra* note 61, at 599.

[64] *See* Marston, *supra* note 60, at 178; Ogunde, *supra* note 60, at 81.

[65] 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-

three years, most businesses can save nearly 30% in IT-related expenditures by utilizing cloud-based services rather than installing their own server and information technology infrastructure.[66] During their first three years businesses can also readily expand or contract their cloud services to meet their growing or shrinking business, reducing risk.[67] Cloud-based services also grant new businesses access to 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.[68] Services include design of a part or a system, part production, experimentation within a system, and simulation and modeling, just to name a few.[69] 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[70] cycle can be described as involving the following stages: 1) basic research, 2) invention & prototyping, 3) product[71]

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are-embracing-cloud-computing-silver-linings?zid=291&ah=906e69ad01d2ee51960100b7fa502595.

[66] McKendrick, *supra* note 65.

[67] 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/.

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

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

[70] 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, 97-98 (1953).

[71] We use “product” for convenience; a service is also included.

development, 4) obtaining funding, and 5) marketing & distribution.[72] Of course, the innovation cycle is not purely linear; there are many feedback loops among the stages.[73] Although there can be many additional stages or sub-stages, this simplified model is sufficient to analyze recent and emerging technologies' effects on the costs and risks of innovation.[74]

After giving an overview of each innovation stage, this Part will demonstrate how technology has and will continue to dramatically lower the costs of each stage. To give force to our assertion, and given the authors' expertise, this Part provides robust discussion of the cost savings from 3D printing. The Part also provides examples of other cost-saving technologies; although space constraints require that we do 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 Einstein's theory of relativity and the mass-energy equivalence ($E=mc^2$) or Faraday's contributions to electromagnetism. Although basic research is an important component of innovation, it rarely leads *directly* to immediate technological change.[75] Rather, it adds to the

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[72] Support for our stages can be found in numerous sources. *See, e.g.*, RESEARCH IN INDUSTRY: ITS ORGANIZATION AND MANAGEMENT 4 fig.1 (C.C. Furnas ed., 1948) (listing fundamental research, applied research, development, and production); Maclaurin, *supra* note 70, 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.") (internal quotation marks omitted); Sichelman, *supra* note 8, at 349-53.

[73] *See, e.g.*, 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).

[74] *See* Margherita Balconi et al., *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).

[75] Edwin Mansfield, *Academic Research and Industrial Innovation*, 20 RES. POL'Y 1, 11 (1991) (finding that only about 10% of the new products and processes studied "could not have been developed (without substantial delays) without recent academic research"); Maclaurin, *supra* note 70, at 99 ("Pure science rarely leads *directly* to patentable invention or to immediate technological change.").

cumulative storehouse of fundamental knowledge necessary to employ and advance the remaining stages of innovation.[76]

1. **3D Printing**

The rise of 3D printing has the ability to reduce significantly the costs of basic research by a) reducing the costs of scientific hardware by a factor of 10 to 100 and b) 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.[77] This slows the rate of scientific development in every field. Historically, the scientific community had to choose one of two sub-optimal paths to participate in state-of-the-art experimental research: 1) purchase high-cost proprietary tools[78] or 2) develop equipment largely from scratch in their own labs, which often involve 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.[79] The highly sophisticated and customized scientific equipment is being developed as free and open-source hardware (FOSH)[80] similar to free and open source software (FOSS).[81] FOSH provides the "code" for

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[76] Kline, *supra* note 73, at 44; Mansfield, *supra* note 75, at 11 (finding, with conservative estimates, that the social rate of return from academic research during 1975-78 to be 28%).

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

[78] 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.

[79] Joshua M. Pearce, *Building Research Equipment with Free, Open-Source Hardware*, 337 SCIENCE 1303 (2012) [hereinafter Pearce, *Building Research Equipment*].

[80] Daniel K. Fisher & Peter J. Gould, *Open-Source Hardware Is a Low-Cost Alternative for Scientific Instrumentation and Research*, 1 MODERN INSTRUMENTATION 8 (2012); *see also* CHRIS ANDERSON, MAKERS: THE NEW INDUSTRIAL REVOLUTION 107-15 (2012).

[81] FOSS is 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

hardware including the bill of materials, schematics, instructions, CAD designs, and other information needed to recreate a physical artifact. Similar to what is seen in FOSS development,[82] FOSH leads to improved product innovation in a wide range of fields.[83] 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.[84]

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 one hundred dollars.[85] 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.[86] The designs have already been open-sourced for a 3D printable 96-well plate strip tube magnet rack that holds $6 magnets,[87] among several other magnetic rack designs.

To understand how expensive scientific equipment normally is, consider that it is possible to economically justify the purchase of a $500 open-source RepRap 3D printer[88] by 3D printing a single standard commercial magnetic rack. The 3D printer, which can pay for itself by

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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).

[82] 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 (2008); OPEN SOURCES: VOICES OF THE OPEN SOURCE REVOLUTION (Chris DiBona et al. eds., 1999); JOHAN SODERBERG, HACKING CAPITALISM: THE FREE AND OPEN SOURCE SOFTWARE MOVEMENT (2008); Karim R. Lakhani & Eric von Hippel, *How Open Source Software Works: "Free" User-to-User Assistance*, 32 RES. POL'Y 923 (2003); Eric Raymond, *The Cathedral and the Bazaar*, 12 KNOWLEDGE, TECH & POL'Y 23 (1999).

[83] There are dozens of examples in different fields. *See, e.g.*, PEARCE, OPEN-SOURCE LABS, *supra* note 77; Fisher & Gould, *supra* note 80; Christoph Hienerth et al., *User Community Vs. Producer Innovation Development Efficiency: A First Empirical Study*, 43 RES. POL'Y 190 (2014).

[84] *See* PEARCE, OPEN-SOURCE LAB, *supra* note 77.

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

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

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

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

making one piece of lab equipment, can then be used to 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 colorimeter to do COD measurements[89] for under $50, replacing similar hand-held tools that cost over $2,000.[90]
- Civil engineers can spend about $60 to make a tool for nephelometry, replacing another ~$2,000 tool.[91]
- 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.[92]
- Biologists can print a syringe pump and automate it for under $100 replacing traditional syringe pumps that range from $250 to over $5000.[93]

As each of the designs can be replicated for little more than the cost of materials, the economic value for the scientific community can be staggering: within a month of the release of the open source syringe pump designs the scientific community saved over $1 million in high-end syringe pump purchases.[94] Moreover, scientists are pushing ever more complex tools, such as the open mesoscopy,[95] and are using 3D printing to

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[89] 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.

[90] Gerald C. Anzalone et al., *Open-Source Colorimeter*, 13 SENSORS 5338 (2013).

[91] Bas Wijnen et al., *Open-Source Mobile Water Quality Testing Platform*, 4 J. WATER, SANITATION & HYGIENE FOR DEV. 532 (forthcoming 2014). Nephelometry refers to the measurement of the size and concentration of particles in a liquid by analysis of light scattered by the liquid.

[92] Pearce, *Building Research Equipment*, *supra* note 79. 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.

[93] Bas Wijnen, et al., *Open-source Syringe Pump Library*, PLoS ONE 9(9): e107216 (2014). 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.

[94] Joshua M. Pearce, *Quantifying the Value of Open Source Hardware Development*, 6 MODERN ECON. 1, 1-11 (2015).

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

print animal and human tissue.[96] Now that open-source 3D bioprinting is possible with a range of technologies,[97] these types of fully open-source, 3D printing-enabled technologies are emergent.

In addition, chemists have begun to experiment with making 3D printable reactionware,[98] liquid handling[99] and 3D printable microfluidics[100] 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.[101] Even top-end equipment is becoming open-source, such as an $800 microscope that replaces an $80,000 conventional equivalent.[102] 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 the discovery, innovation, and productivity, and to keep the U.S. competitive internationally.[103] STEM education costs more than most traditional classroom instruction in large part because of the high costs of scientific hardware and lab supplies discussed above. The high costs often limit access to exciting and engaging labs in both K-12 and university

[96] L. 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 (2012).
[97] Patrik, *DIY BioPrinter*, INSTRUCTABLES, http://www.instructables.com/id/DIY-BioPrinter/ (last visited Oct. 12, 2014).
[98] Mark D. Symes et al., *Integrated 3D-Printed Reactionware for Chemical Synthesis and Analysis*, 4 NAT. CHEMISTRY 349 (2012).
[99] 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 (2013).
[100] Philip J. Kitson et al., *Configurable 3D-Printed Millifluidic and Microfluidic 'Lab on a Chip' Reactionware Devices*, 12 LAB ON CHIP 3267 (2012).
[101] Joshua M. Pearce, *An Algorithm for Generating and Identifying Public Domain 3-D Printing Materials* (2015) (on file with author).
[102] *Open Lab Tools*, U. CAMBRIDGE, http://openlabtools.eng.cam.ac.uk/ (last visited Oct. 13, 2014).
[103] Anthony P. Carnevale *et al.*, *STEM*, GEORGETOWN U. CENTER ON EDUC. & WORKFORCE (Oct. 20, 2011), http://cew.georgetown.edu/STEM/.

education, weakening recruitment of future STEM talent.[104] The upshot is about 4 million unfilled jobs in the U.S. due to inadequate numbers of college graduates in STEM-related disciplines.[105]

FOSH concepts can emphatically reduce costs for K-12 STEM education, resulting in tens of millions of dollars saved.[106] This would increase access to STEM training and increase recruitment, leading to a virtuous cycle for future innovation.[107]

2. <u>**Other Technologies**</u>

Here we briefly mention 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.

Cloud computing can provide cheaper and better tools for basic scientific research.[108] Among other things, cloud computing allows individuals to access large-scale computational resources without the need to by a mainframe computer.[109] By paying for these services only on an as-needed basis, researchers gain access and save money.

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

[105] *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 Oct. 13, 2014).

[106] *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).

[107] *See* Rachel Goldman et al., *Using Educational Robotics to Engage Inner-City Students with Technology*, ICLS '04 PROCEEDINGS 6TH INT'L CONF. ON LEARNING SCI., Jun. 22, 2004, at 214; J. Irwin, et al. *The RepRap 3-D Printer Revolution in STEM Education*, 121st ASEE Annual Conference and Exposition, Indianapolis, IN. Paper ID #8696 (2014), available at http://www.asee.org/public/conferences/32/papers/8696/view; J. Kentzer et al., *An Open Source Hardware-Based Mechatronics Project: The Replicating Rapid 3-D Printer*, 2011 MECHATRONICS (ICOM), 2011 4TH INT'L CONF. ON 1.

[108] *Understanding Cloud Computing for Research and Teaching*, http://escience.washington.edu/get-help-now/understanding-cloud-computing-research-and-teaching (last visited Jan. 18, 2015) (describing the benefits of cloud computing for research).

[109] *See, e.g.*, Langmead *et al.*, *Cloud-scale RNA-sequencing Differential Expression Analysis with Myrna*, 11 GENOME BIOLOGY 1, 1-11 (2010), available at

In addition, FOSS has obvious abilities to lower costs to researchers because the software is free. A myriad of specialized programs have proliferated for researcher use across a variety of disciplines.[110] More broadly than direct application to basic research, but no less important, FOSS components like Linux, MySQL, etc., provide an inexpensive means for individuals, researchers, groups, and even countries to use free, sophisticated technology and even develop an entire technological infrastructure.[111]

The biotechnology sector includes its own open source movement that can provide researchers with cheap access to basic research tools.[112] Specialized fields such as synthetic biology are likewise attempting to foster open innovation models.[113] Even apart from open source models, the costs of some basic biotechnology functions have decreased

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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); Medical College of Wisconsin, *Cloud Computing Brings Cost Of Protein Research Down To Earth*, SCIENCEDAILY (Apr. 13, 2009), www.sciencedaily.com/releases/2009/04/090410100940.

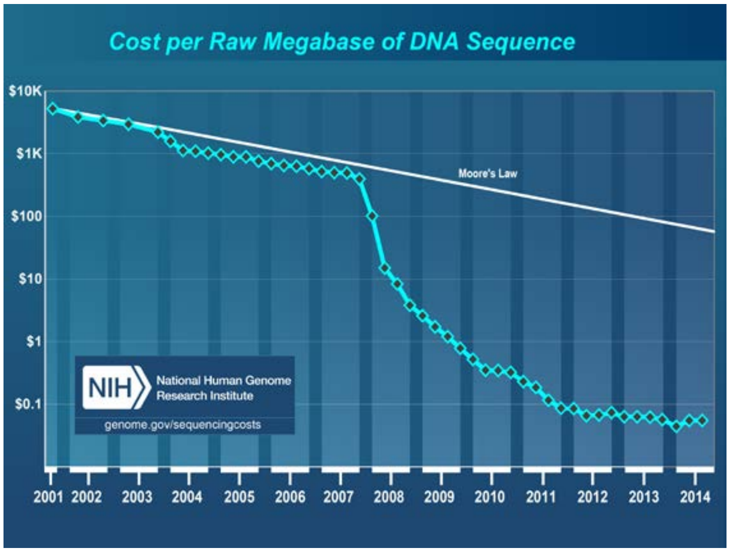
[110] *See, e.g.*, S. L. Delp *et al*., *OpenSim: Open-Source Software to Create and Analyze Dynamic Simulations of Movement*, 54 IEE TRANSACTIONS ON BIOMED. ENG'G. 1940 (2007) (describing an open source software tool to study human movement); Paolo Giannozzi et al., *QUANTUM ESPRESSO: A Modular and Open-source Software Project for Quantum Simulations of Materials*, 21 J. PHYSICS CONDENSED MATTER 395502 (2009) (describing an integrated suite of computer codes for electronic-structure calculations and materials modeling).

[111] SAMIR CHOPRA & SCOTT D. DEXTER, DECODING LIBERATION: THE PROMISE OF FREE AND OPEN SOURCE SOFTWARE xv, available at http://epicenter.media.mit.edu/~mako/foss-reading/DLbook.pdf ("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").

[112] *See* JANET HOPE, BIOBAZAAR (2008) (describing the fledgling open source biotechnology movement and exploring whether it can expand to a robust phenomenon); 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.").

[113] 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.").

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 a million DNA base pairs was about $1,000 in 2004, by 2011 the cost had fallen to an amazing $0.10.[114] Knowing the DNA sequences of an organism is a basic research step that must occur before various follow-on research can occur.[115]



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,[116] and ends roughly with the creation of detailed design drawings and an initial working prototype.[117]

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[114] Kris Wetterstrand, *DNA Sequencing Costs: Data from the NHGRI Genome Sequencing Program (GSP)*, http://www.genome.gov/sequencingcosts/ (last visited Feb. 19, 2015).

[115] *See* KEVIN DAVIES, THE $1,000 GENOME: THE REVOLUTION IN DNA SEQUENCING AND THE NEW ERA OF PERSONALIZED MEDICINE 12-13 (2010) (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 visited Feb. 19, 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.").

[116] Sichelman, *supra* note 8, at 348-50.

[117] Kline, *supra* note 73, at 37 (discussing the creation of design drawings and prototypes); Maclaurin, *supra* note 70, at 102 ("invention . . . discloses an operational method of creating something new.").

1. 3D Printing

3D printing enables design ideas developed in CAD to be easily fabricated on the same day. The printed 3D prototype can then be tested and studied and refined quickly.[118] The finalized design can then either be manufactured by some other process or fabricated by a 3D printer for use. In contrast, traditional methods of making prototypes (e.g. model making by hand and machining) are both time-consuming and expensive.[119]

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 general public.[120] Invention and prototyping has thus been re-democratized. 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.

For example, consider invention and prototyping in heat exchanger design. Traditionally heat exchangers are made from metal, which transfers heat well. Polymers (e.g., garbage bags), with relatively poor thermal conductivity, are rarely considered as a material for heat exchangers. But if 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.[121]

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.[122] The original prototype for this exchanger cost $3,000. To reduce costs, the team invented an open-source, polymer laser

[118] *See* ANDREAS GEBHARDT, RAPID PROTOTYPING (2003).

[119] CHEE KAI CHUA ET AL., RAPID PROTOTYPING: PRINCIPLES AND APPLICATIONS 14 (3d ed. 2010).

[120] Until a few years ago even the simplest 3D printer using fused filament cost over $20,000 and the advanced version costs hundreds of thousands of dollars. For example, a powder metal EOS 3D printer currently starts at over $500,000. EOS, http://www.eos.info/en (last visited Oct. 13, 2014).

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

[122] 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 (2012).

welding system from customized 3D printed parts.[123] The open-source laser welder was far less costly than the custom commercial systems that manufactured the original prototype heat exchanger.[124]

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 28-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[125] to heat recovery ventilator in cars and trucks.[126] This example is but one of thousands.[127]

It bears emphasizing that low-cost, open-source 3D printing drives innovation not only among professional engineers and scientists, but also the general public made up of an army of hobbyists, prosumers,[128] "makers",[129] DIYers, backyard tinkerers, and even children. A new, vast

[123] PEARCE, OPEN-SOURCE LAB, *supra* note 77.

[124] The savings on the capital equipment, however, are trivial compared to the cost savings in making new heat exchanger designs: about $2,950 is saved every afternoon that the system is run to make a new design. This savings, however, relates more to the product development cycle, which is discussed in Part II.C., *infra*.

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

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

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

[128] Prosumer is a portmanteau of producer and consumer. The ideas being that the consumer produces many of their own goods. ALVIN TOFFLER, THE THIRD WAVE: THE CLASSIC STUDY OF TOMORROW 292 (1984).

[129] 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, "[w]hether as hobbyists or professionals, makers 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." *See Leading the Maker Movement*, MAKERMEDIA, http://makermedia.com/ (last visited Oct. 13, 2014). As would be excepted makers are heavily involved with 3D printing – most notably making up the majority of the developmental work on the RepRap project. See REPRAP, http://reprap.org/wiki/RepRap (last visited Oct. 13, 2014), where

collection of free and open-source CAD programs enable everyone with an interest to "play" 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 which have a "share alike" rider,[130] which demands that those that build on the concept re-share their work with the community under the same license. To get a feel for the momentum, consider that Thingiverse,[131] but one of dozens of free 3D printable design web site repositories, currently has over 690,000 free designs, and an exponential increase in the rate of available, free 3D printable designs has already been documented.[132]

2. Other Technologies

Other technologies also reduce the costs of invention and prototyping, especially for digital-based technology start-ups.[133] 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. Prototype apps (often called beta-tests) can be created by remote independent developers accessible through on demand Internet interfaces.[134] Moreover, crowdsourcing platforms have emerged that assist in app creation, among other areas.[135] Simple versions of apps and websites can be created in a matter of days.[136]

individuals working as hobbyists have contributed the large majority of innovations and variations.

[130] *See, e.g.*, CREATIVE COMMONS, https://creativecommons.org/licenses/by-sa/3.0/us/ (last visited Oct. 13, 2014).

[131] MAKERBOT THINGIVERSE, http://www.thingiverse.com/ (last visited Oct. 13, 2014).

[132] Wittbrodt et al., *supra* note 88.

[133] 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, *How Much Does it Cost to Develop an App?*, FUELED (Oct. 31, 2013), http://fueled.com/blog/how-much-does-it-cost-to-develop-an-app/ (estimating that the average app costs about $120,000-150,000 to develop and noting that a proof-of-concept app can be created even more cheaply).

[134] *See, e.g.*, *Online Labour Exchanges*, THE 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 [and on-demand service provider] last year were in web programming and mobile apps.").

[135] *See, e.g.*, http://appirio.com/services/crowdsourcing/ (last visited Jan 23, 2015).

[136] *Creating a Business*, ECONOMIST (Jan. 18, 2014), http://www.economist.com/news/special-report/21593581-launching-startup-has-

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.[137] The company sees itself as "a modern invention machine."[138]

As the costs of DNA sequencing and synthesis continue to drop, they will help produce a stream of biochemical inventions. This in turn will call for mature synthetic biology and chemistry processes so that companies can construct their desired molecules quickly and cheaply.[139] 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.[140]

While nascent, these chemical and biological platforms are growing. So-called "biohackers" meet around the world in "hackerspaces" where even lay people can build simple biological machines.[141] 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.[142] As one Harvard Medical School professor stated, "biological carbon is the silicon of this

become-fairly-easy-what-follows-back-breaking ("A quick prototype can be put together in a matter of days").

[137] 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/.

[138] *Id*.

[139] *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).

[140] *See id*.; Katherine Xue, *Synthetic Biology's New Menagerie*, Harvard Magazine 42, 42-43, (Sept-Oct. 2014).

[141] http://biohackspace.org/ (last visited Feb. 3, 2015) (describing a biohackerspace in London); http://www.biohackers.la/ (last visited Feb. 3, 2015) (describing a biohackerspace in Los Angeles). *See also* Gaymon Bennett *et al.*, *From Synthetic Biology to Biohacking: Are We Prepared?*, 27 NATURE BIOLOGY 1109, 1109-1111 (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).

[142] Xue, *supra* note 140, at 42.

century,"[143] 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.[144] Molecular modeling software mimics and predicts how molecules will act, thus reducing the need for live experiments.[145] Although molecular modeling has not yet made large impacts on pharmaceutical or chemical inventions, commentators believe that increased computing power will increase its impact.[146]

C. Product Development

Generally speaking, the product development stage turns an initial prototype into a market-ready product.[147] 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.[148] In many cases, an ideal product development process would continually refine the prototype as knowledge is gained from technical and market studies.[149] In such an environment, it is important to have quick and inexpensive incorporation of the refinement process.[150]

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

[143] *Id*.

[144] 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.

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

[146] Watson, *supra* note 144, at 27.

[147] Maclaurin, *supra* note 70, at 105.

[148] Kline, *supra* note 73, at 37-38 (discussing product development and feedback links).

[149] *See* Stephen J. Kline & Nathan Rosenberg, *An Overview of Innovation*, *in* THE POSITIVE SUM STRATEGY 275, 289-91 (Ralph Landau & Nathan Rosenberg eds., 1986).

[150] *Id.* at 296 (noting that "speed of turnaround is a critical factor in the effectiveness of innovation").

updated and adjusted based on user feedback, technical assessment, and the like.[151] Rarely is a product design perfect the first time; it must go through dozens or even hundreds of iterations before going to market.[152]

Whereas traditional manufacturing techniques (such as casting, forming, joining, machining, and molding) might be slow and/or 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 costs, and shipping time during the product development stage. The benefits of low-cost, immediate prototyping are even changing the way large, wealthy firms—that 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.[153]

After creating and improving numerous prototypes, a company may at some point be ready to sell a finished product. Under traditional manufacturing frameworks, deciding whether to formally launch a product was a risky proposition, because traditional manufacturing techniques are capital intensive (e.g., require expensive up-front costs such as tooling of machines).[154] If the product needed to be modified, much or all of these expenses would be lost.[155] 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 add 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

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

[152] *See* Kline & Rosenberg, *supra* note 149, at 289-91.

[153] WOHLERS & GORNET, *supra* note 26, at 5.

[154] *See* 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.").

[155] 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 be canceled, the product development process will become a sunk cost.").

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 manufacturer for short runs, customized products, and a large number of polymer products.[156] In addition, 3D printers are versatile, so if a product needs modification, the printer can print the modification without expensive and slow retooling.

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 even 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 is then printed and shipped to them the next day.[157]

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 via the Internet grease the wheels of innumerable product development projects. Beyond these background effects, however, countless industries have seen their product development costs decrease.

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[156] Wittbrodt et al., *supra* note 88.

[157] *See, e.g.*, 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 (Jun. 4, 2013), http://3dprintingindustry.com/2013/06/04/design-your-personalized-3d-printable-jewellery-online-suuz-com/.

Perhaps no industry has seen costs fall as much as digital-based companies.[158] For example, in 1999 Naval Ravikant, a co-founder of Epinions, a website for customer reviews, required six months of time and $8 million in venture capital funds to buy computers, license database software, and hire eight programmers before he could launch the website. In contrast, just eleven years later, he needed only a few weeks and less than $100,000 when founded AngelList, a social network for startups.[159] 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.[160] Numerous startups have leveraged the availability of free, open-source software, cloud-based computing, and fast Internet speeds to lower their launch costs.[161]

Once the inventor creates the prototype of the digital product, she can iteratively update and improve it in real time. Things like testing, user feedback, and product updates can be performed via the web cheaply and quickly.[162] Whatever server capacity the product requires can be added or subtracted in near real time on the cloud.

Beyond digital products, many physical products can be taken 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 we discussed prototyping.[163] These companies will take basic ideas and turn them into finished products on behalf of the inventor.[164] The presence of nimble, smaller-

[158] Coyle & Green, *supra* note 133, at 155 ("Over the past decade, the costs of launching a new technology start-up have fallen precipitously.").

[159] *Creating a Business*, ECONOMIST (Jan. 18, 2014), http://www.economist.com/news/special-report/21593581-launching-startup-has-become-fairly-easy-what-follows-back-breaking.

[160] *Id*.

[161] Coyle & Green, *supra* note 133, at 155-57.

[162] For testing, websites such as usertesting.com provide a crowd-sourcing means for testing products. *See, e.g.,* http://www.usertesting.com/about-us (last visited Dec. 16, 2014).

[163] *See supra* note 137 and accompanying text.

[164] *See* Steve Lohr, *The Invention Mob, Brought to You by Quirky*, NY TIMES (Feb. 14, 2015), http://www.nytimes.com/2015/02/15/technology/quirky-tests-the-crowd-based-creative-process.html (describing Quirky's business).

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 bio-modules aid in invention and prototyping,[165] they can aid in building finished products. One company even offers an inexpensive method to print DNA.[166] Similarly, molecular modeling can be used not only to identify lead pharmaceutical compounds, but also to help optimize lead compounds into a molecule suitable for clinical trials.[167]

D. Obtaining Funding

In reality, the "stage" of obtaining funding is sprinkled throughout the whole process. Obviously, funding is extremely important because without some source of capital, most innovations cannot proceed.[168] Start-ups incur costs in the stages mentioned previously, and on the marketing and distribution, discussed in the next sub-part. Employees and consultants must be paid and materials and equipment must be purchased. 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.[169] 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 (for new companies attempting to overcome capital constraints anyway) is venture capital.[170] Other traditional sources include government grants, angel investors, and even friends and family. For

[165] *See supra* notes 141-143 and accompanying text.

[166] 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/.

[167] Watson, *supra* note 144, at 27.

[168] Maclaurin, *supra* note 70, 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.").

[169] *See* Eldred & McGrath, *supra* note 155, 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.").

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

innovations developed within an existing large firm, the source of funding is most often the firm itself.

One innovation that directly affects 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 via the Internet.[171] The concept is disrupting the business of funding innovations and is empowering individuals and small businesses.[172] 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.[173] Many crowdfunding platforms exist already,[174] including Kickstarter, Indiegogo, Fundable, and Peerpackers.

Although crowdfunding directly impacts the funding process, the new and emerging technologies such as 3D printing and the Internet have an important indirect effect.[175] 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.[176] Instead, innovators can raise adequate capital from alternative sources, such as alternative venture capital-like funding,[177] crowdfunding, and even friends and family. 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.

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

[172] 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/ (stating that crowdfunding is "disrupting the way enterprises, entrepreneurs, non-profits, and individuals raise capital").

[173] THOMAS E. VASS, ACCREDITED INVESTOR CROWDFUNDING: A PRACTICAL GUIDE FOR TECHNOLOGY (2014) (describing strategies for technology companies to raise money from accredited investors via crowdfunding).

[174] *See, e.g.*, CROWDSOURCING.ORG, http://www.crowdsourcing.org/directory (last visited Feb. 23, 2015).

[175] We note also 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, THE ART OF INNOVATION 112 (2001) ("But a prototype is almost like a spokesperson for a particular point of view, crystallizing the groups' feedback and keeping things moving.").

[176] *See* Coyle & Green, *supra* note 133, at 157-76 (describing contractual innovations to create alternative funding mechanisms).

[177] *See id*.

Second, less formal avenues for obtaining funding are less cumbersome and intimidating, meaning that innovators are less likely to give up.

E. Marketing and Distribution

Once a business decides it will launch a product, it must develop a marketing campaign and distribution strategy.[178] Marketing includes at least the process of promoting one's goods or services to prospective customers through advertising and other promotional methods.[179] Distribution relates to how a company will ensure that prospective customers are able to locate, obtain, and use its products and services.[180]

1. <u>3D Printing</u>

3D printing technology is likely to have rather minor effects on product promotion, but will bring a sea 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 out 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.[181] Technical commentators likewise discuss how radically the distribution models will change, noting also that economic models may change.[182] Thus, for

[178] *See, e.g.*, Kline, *supra* note 73, at 37 fig.2 (showing "distribute and market" and the final stage of innovation).

[179] JAMES BURROW, MARKETING 6 (3d ed. 2009).

[180] *Id*.

[181] See, for example, *The Third Industrial Revolution*, ECONOMIST, Apr. 21, 2012, *available at* http://www.economist.com/node/21553017, which is an entire special issue investigating what the editors refer to as a third industrial revolution brought on by digital manufacturing and 3D printing.

[182] *See* NEIL A. GERSHENFELD, FAB: THE COMING REVOLUTION ON YOUR DESKTOP—FROM PERSONAL COMPUTERS TO PERSONAL FABRICATION (2005); 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*, 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., *3D Printing of Open Source Appropriate Technologies for Self-Directed Sustainable Development*, 3 J. SUSTAINABLE DEV. 17 (2010) [hereinafter Pearce et al., *OSAT*] (discussing the use of 3D printers to help the developing world to manufacture); Pearce, *The Case*, *supra* note 127.

example a single CAD design of a high-value product like a water pump part can be freely copied by thousands of individuals around the globe, who can then use 3D printing (e.g. distributed manufacturing) to make the device for only the cost of raw materials.[183] For those unable or unwilling to buy a 3D printer, many on-line 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.[184]

Some will doubt whether the technology will ever achieve such dramatic impacts.[185] 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 RepRap 3D printers discussed in this Article print primarily in plastics (polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS)), which is clearly limiting.

On the other hand, many other materials have been demonstrated (including ceramics, flexible polymers, and wood-fiber composites) at the DIY level,[186] much more sophisticated 3D printing materials have been shown in the academic literature,[187] and it appears clear that a much wider selection of materials will be made possible for 3D printers in the near future.[188] For example, RepRaps capable of printing in metal are just now

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[183] *See* Pearce et al., *OSAT*, *supra* note 182.

[184] *See, e.g.*, SHAPEWAYS, http://www.shapeways.com/ (last visited Oct. 13, 2014); PONOKO, https://www.ponoko.com/ (last visited Oct. 13, 2014); MAKEXYZ, http://www.makexyz.com/ (last visited Oct. 13, 2014).

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

[186] *RepRap Materials*, APPROPEDIA, http://www.appropedia.org/RepRap_materials (last visited Oct. 13, 2014).

[187] *See, e.g.*, Thomas A. Campbell & Olga S. Ivanova, *3D Printing of Multifunctional Nanocomposites*, 8 NANOTODAY 119 (2013); A. Ovsianikov et al., *Laser Printing of Cells Into 3D Scaffolds*, 2 BIOFABRICATION (2010); Gavin MacBeath et al., *Printing Small Molecules as Microarrays and Detecting Protein-Ligand Interactions En Masse*, 121 J. AM. CHEMICAL SOC'Y 7967 (1999); Harpreet Singh et al., *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 (2005).

[188] E. Hunt et al., *Polymer Recycling Codes for Distributed Manufacturing with 3-D Printers*. Resources, Conservation & Recycling (2015). DOI: 10.1016/j.resconrec.2015.02.004.

emerging,[189] and a low-cost printer capable of even printing in steel[190] and aluminum.[191] 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 effected innovation in marketing and distribution is the Internet. On the marketing front, it made possible on-line 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.[192] 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.[193]

In the distribution realm, the Internet helped give rise to innovations such as paperless delivery of tickets and payments[194] and quick delivery of physical goods.[195] For digital-based innovation, the presence of increased Internet speeds, ubiquitous mobile computing, and social media networks all allow companies to distribute their products and

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

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

[191] Amber S. Haselhuhn et al., *Substrate Release Mechanisms for Gas Metal Arc 3-D Aluminum Metal Printing*. 1 3D PRINTING AND ADDITIVE MANUFACTURING, 204, 204-209 (2014).

[192] *See, e.g.*, Yongmin Chen, *Marketing Innovation*, 15 J. ECON. & MGMT. STRATEGY 101, 101 (2006).

[193] DAN ZARRELLA, THE SOCIAL MEDIA MARKETING BOOK 1-2, 7 (2009).

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

[195] *See* Jack D. Becker *et al.*, *Electronic Commerce and Rapid Delivery: The Missing "Logistical" Link*, AMCIS 1998 Proceedings (1998), *available at* http://aisel.aisnet.org/amcis1998/94 (predicting the future of quick delivery for electronic commerce purchases); Joseph P. Bailey & Elliot Rabinovch, *Internet Book Retailing and Supply Chain Management: An Analytical Study of Inventory Location Speculation and Postponement*, 41 J. TRANSP. RES. PART E, 159, 159-77 (2005). Readers may be familiar with Amazon's "Prime" delivery, which provides two-day shipping on many goods. *See* http://www.amazon.com/gp/prime/ref=footer_prime (last visited Jan. 24, 2015).

services rapidly and at potentially unlimited scale.[196] Of course, cloud computing is itself a powerful example of dramatically reduced distribution costs—the software is stored remotely and delivered only digitally.

F. Summary

In sum, technology is drastically lowering the costs of innovation across a wide range of technologies. All the technology, of course, is not yet mature. But it is already having profound effects, and these will grow.

We recognize a potential criticism of our technology discussion herein. Specifically, it can be questioned whether we "cherry picked" the technologies that most support our recommendations while ignoring contrary evidence of *increased* innovation costs in other technologies. We freely admit that the technologies we describe herein represent to us some of the most powerful examples of decreased innovation costs. But rather than cherry picking them to support our recommendations, our recommendations follow from our understanding of technology and its effects. Simultaneously, we are not aware of any technology that has drastically increased the costs of innovation. Thus, we believe that the average cost of innovation has decreased, and will continue to dramatically do so.

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

In the preceding Part, we demonstrated that the costs of innovation are decreasing, often dramatically, across many technology sectors. In this Part we explore the consequences of this phenomenon, arguing that the decreased cost of innovation impel a weakening of the patent system. Below we show that our 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, we then provide concrete observations about how the patent system should be changed. First, we query what magnitude of change the patent system requires. Second, we propose 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-

[196] Coyle & Green, *supra* note 133, at 156-57.

invent theory, which we 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.[197] Note that under this theory, patents are granted for *inventions*, and inventing is an early stage in the innovation cycle.[198] Thus, what patents most directly incentivize are basic research and inventing.[199] As we demonstrated, technologies are reducing both of these costs. Following the economic model of the incentive theory therefore suggests that less incentive is needed because less costs need to be recouped. To lower the incentives, one should weaken the patent system because doing so will align incentives with needs.

Weakening patents has the important salutary effect of decreasing their harmful effects. First, consider the deadweight loss harm associated with monopoly pricing.[200] Weaker patents diminish this deadweight loss by reducing the power of the patentee. For example, if lawmakers weaken patents by shortening their term, the period of monopoly pricing is shortened. Alternatively, if lawmakers weaken patents by narrowing their scope, there is a greater chance that viable non-infringing substitutes will be developed.

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.[201] Although the improver can theoretically obtain a mutually-beneficial license from the owner of the first patent, various transaction costs often prevent this.[202] 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.

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[197] *Id*.

[198] 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.

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

[200] For a discussion of monopoly pricing, *see supra* notes 6-7 and accompanying text.

[201] *See* Merges & Nelson, *supra* note 1, at 870 (noting that "broad patents could discourage much useful research").

[202] *See, e.g.*, *id*. at 874 n.146 (cataloguing literature showing the high costs of licensing); Sichelman, *supra* note 8, at 368-69 (reviewing transaction costs that can stifle commercialization).

An alternate theory of the patent system, the prospect theory, also suggests that patent should be weakened 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 post-invention expenditures (i.e., the commercialization expenses of product development and marketing).[203] Recognizing the indirect nature of these incentives, the prospect theory and related commercialization theories[204] suggest that patents might under-incentivize commercialization expenditures unless patents are sufficiently strong.[205] In other words, patents need to be stronger than what is needed merely to incentivize *inventions*; they need to be strong enough to incentivize *commercialization* costs.[206] The prospect theory has been much debated,[207] but to the extent it and related commercialization theories are accurate, they support our call for weaker patents. Simply put, the decreased costs of product development, marketing, and distribution we identified in Part II demonstrate that less incentive is needed to incur those costs. Where lower incentives are needed, lawmakers can weaken patents, thereby lessening the harms they cause while maintaining optimal incentives for innovation.

Capitalizing on insights about post-invention 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 post-invention commercialization efforts regardless of the presence of a traditional invention-based patent.[208] Such a system would provide, however, the

[203] *Id*. at 367-68. *See also* Robert P. Merges, *Commercial Success and Patent Standards: Economic Perspectives on Innovation*, 76 CAL. L. REV. 805, 809 (1988) ("[T]he patent system rewards innovation only indirectly, through the granting of patents on inventions.").

[204] 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).

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

[206] *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.").

[207] *Id*. at 441-42 (describing criticisms).

[208] Sichelman, *supra* note 8, at 400-10.

possibility for monopoly prices tied to a specific commercial embodiment.[209] 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 post-invention innovation costs decrease. Given the administrative costs of initiating such a radical new system, our observations about innovation costs suggest the case for such a new system is much diminished.

Finally, we note that our observations of decreased innovation costs also impact non-economic 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.[210] Under such a theory, however, the size of the reward should be proportional to the labor contributed.[211] Because the average costs (here, labor) of innovation are decreasing, the deserved reward should likewise be smaller (in the form of a weaker patent).

In sum, 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. We explore these questions 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 our work is not empirical in nature, and we do not know the precise values of the reductions to innovation costs. And even if we did, we would not solve the problem of

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[209] Professor Sichelman seeks to avoid invention patents' impediment to follow-on innovation by requiring very narrow commercializing claim scope, *id*. at 401, but 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.

[210] Hughes, *supra* note 4, at 297-310.

[211] LAWRENCE C. BECKER, PROPERTY RIGHTS 53 (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.").

the patent system's immense complexity.[212] 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.

As a starting point, however, we suggest a change that is significant enough so that its effects can be ascertained and studied. Too small of a change would be lost in the complex noise of the patent system. Hence, we recommend a change or set of changes that would be roughly equivalent to weakening patents by 25% to 50%.

The remainder of this subpart analyzes various key additional considerations we weighed and we believe policymakers should weigh when considering the magnitude of the change to the patent system.

1. **Non-Monetary Incentives to Innovate Favor a Weaker Patent System**

Our argument for weaker patents is strengthened by a growing body of literature using insights from psychology and sociology to study the patent system.[213] One insight from this literature is that people engage in innovative activities not only for pecuniary reasons, but also for non-monetary reasons, including intellectual challenge, recognition, the joy of inventing and solving problems, improving social welfare, or the desire for control and responsibility.[214] Thus, dampening monetary incentives will generally not have a 1:1 effect on overall incentives to innovate.

Pecuniary and non-pecuniary motivations can often work together synergistically.[215] In those cases, the monetary promise of a patent and

[212] *See supra* notes 17-18 and accompanying text.

[213] *E.g.*, 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. L. REV. 1441 (2010); William Hubbard, *Inventing Norms*, 44 CONN. L. REV. 2 (2011); Eric E. Johnson, *Intellectual Property and the Inventive 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.

[214] *E.g.*, Hubbard, *supra* note 213, at 373 (noting that "many 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 (2010) (citing numerous sources that support the hypothesis that inventors are motivated by nonpecuniary rewards).

[215] *See* Mandel, *supra* note 213, 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."). *Accord* Christopher J. Buccafusco

the non-monetary 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 is weakened, the *proportions* of monetary and non-monetary incentives change. The following chart demonstrates this phenomenon on an assumption that a decrease in patent strength by 50% decreases monetary incentives by 50% but does not affect non-monetary incentives.[216]

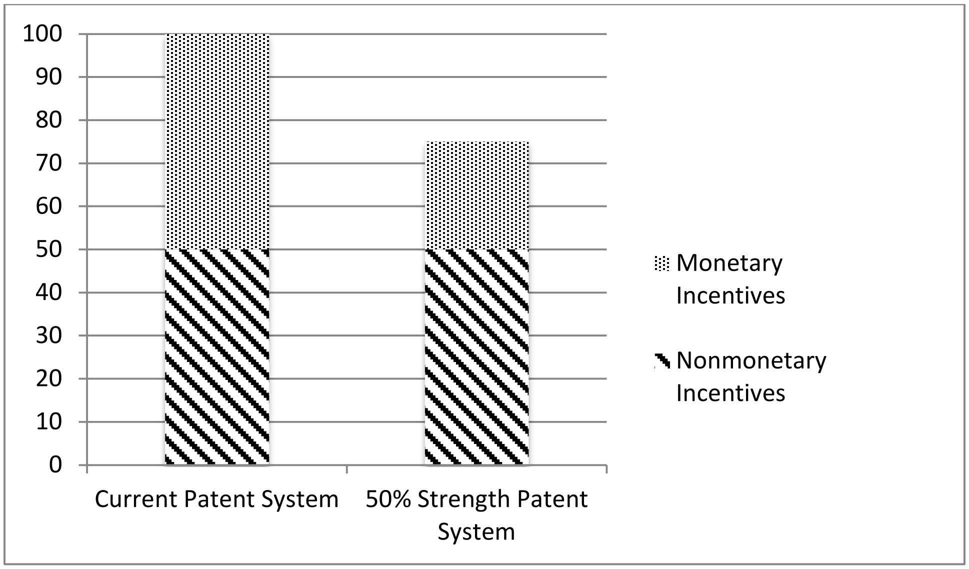

Chart 1: Effect of Changing Monetary Incentives

In the chart, the dot-shaded area represents motivation from monetary incentives and the diagonal-shaded area 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 by 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

et al., *Experimental Tests of Intellectual Property Laws' Creativity Thresholds*, 92 TEX. L. REV. 1921, 1937–39 (2014) (describing how extrinsic motivators sometimes do not undermine creativity). Note that sometimes offering monetary incentives can have the opposite effect. *See* 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. PSYCHOLOGY 549 (2005); Johnson, *supra* note 213, at 671-76 (suggesting that patents are rarely, if ever, necessary to incentivize invention).

[216] As described below, this may be an oversimplification because adjusting patent strength may affect nonmonetary incentives.

we weaken patents by 50% (assuming that the reduction in strength correlates 1:1 with a reduction in monetary incentive). Under this scenario, the inventor continues to have 50 "units" of motivation from nonmonetary sources, but only 25 "units" from monetary sources. Thus, monetary motivation only represents 33% of the inventor's motivation. Importantly, however, whereas patents were weakened by 50%, the inventor's overall motivation only decreased by 25%.

Chart 1 graphically illustrates some intriguing results. Weakening the patent system does not necessarily result in a 1:1 weakening of incentives to innovate. Further, if we assume technology has reduced innovation costs by 50%, then weakening patents by 50% will actually leave a *surplus* of motivation for innovation (i.e., the incentive above 50%) 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, we must distinguish between intrinsic and extrinsic motivators. In the language of psychology, monetary rewards represent an extrinsic motivator, in that they originate outside the inventor.[217] Many non-monetary reasons, such as the love of inventing, represent intrinsic motivations, meaning that they come from within the inventor.[218]

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."[219] The more inventive work is intrinsically motivated, the more likely it will be to bear inventive fruit.[220] Mandel's insight suggests that we must be careful to calibrate patent law so that the extrinsic, monetary incentives do not dominate intrinsic motivation.[221] This suggests that we should not allow

[217] Mandel, *supra* note 213, at 2008.
[218] *Id*.
[219] *Id*. at 2007-08.
[220] *See id*. at 2010.
[221] Mandel focuses on framing activities as intrinsically oriented. *Id*. at 2012. But it is reasonable to believe that stronger patents will tend to dominate intrinsic incentives compared to weaker patents.

the monetary incentives of a patent to be too strong, or else the extrinsic motivation will dominate. As innovation costs decrease, if patents remain the same strength they will represent a stronger monetary incentive because more of the financial returns represent profit. Thus, to avoid allowing the external motivation of patents to dominate intrinsic motivations, which would result in less fruitful inventive activity, patents should be weakened 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.[222] In Hubbard’s view, financial rewards and inventing norms can sometimes work together to encourage invention. For example, protecting inventions via patents (which offer financial rewards) can reinforce inventing norms by signaling a value judgment in favor of inventions.[223]

Hubbard notes that if we abolished patents altogether, it “could be viewed as evidence that invention is longer important in America, thereby reducing social incentives to pursue technological discoveries.”[224] On the other hand, 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 than praiseworthy invention.”[225] 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 of inventing norms. To the extent that inventing norms can be measured and predicted, Hubbard’s observations suggest our 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 is retained demonstrates America continues to value patents.

[222] Hubbard, *supra* note 213, at 378-87.
[223] *Id*. at 390-93.
[224] *Id*. at 408.
[225] *Id*. at 404.

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

The technologies that lower innovation costs can be used not only by innovators, but also by imitators. 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.[226] 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 we described 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.[227] Even 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 cost 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 million to innovate a given product and $500,000 to copy. Assume further that after these technologies the innovation costs was

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[226] *See, e.g.* STEVEN P. SCHNAARS, MANAGING IMITATION STRATEGIES: HOW LATER ENTRANTS SEIZE MARKETS FROM PIONEERS 1 (1994) (noting that imitation 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 be done more often. *E.g.*, Oded Shenkar, *Defend Your Research: Imitation Is More Valuable Than Innovation*, (April 2010) (finding imitation to be a great source of progress), *available at* http://i2ge.com/wp-content/uploads/2012/01/Imitation-instead-of-innovation.pdf.

[227] This assumes the CAD file is not protected by any patents, copyrights, or trade secrets.

$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 two-thirds to one-half the costs of innovating.[228] But 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.[229] 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.[230] Lead-time advantages for original innovators allow them to charge higher profits (assuming no substitute goods exist), establish a reputation, and take advantage of lock-in effects.[231] 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 products look and feel (remember the difficulty you had (or have) when you first switched between a mac and a PC), or when the customer has sunk ancillary costs into adopting a product.[232] Additionally, a positive network effect, which

[228] Richard C. Levin et al., *Appropriating the Returns From Industrial Research and Development*, 1987 BROOKINGS PAPERS ON ECON. ACTIVITY 783, 784; 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 12 (1991), *available at* http://mpra.ub.uni-muenchen.de/26214 (showing that imitation costs were about one-half of innovation costs).

[229] Levin et al., *supra* note 228, at 807-812; Mansfield et al., *supra* note 228, at 910.

[230] *See* Christina L. Brown & James M. Lattin, *Investigating the relationship between time in market and pioneering advantage*, 40 MGMT. SCI., 1361, 1361-69 (1994) (finding that pioneering advantage is related to a brand's length of time in the market).

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

[232] *See id.*

is the phenomenon of a good becoming more valuable to each user as more people use it, can exponentially increase lead-time advantage.[233]

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.[234]

The decrease in lead time for copycat products implies that patents remain useful in protecting innovation and should not be abolished. Our proposal meshes with this observation, as we suggest 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, that it will cause companies to leave the United States in favor of countries with stronger patents.[235] The argument that the U.S. will lose competitiveness suffers from various flaws. First, in certain industries, such as where innovations costs are low or alternate means of protection exist, patents are not perceived as very important.[236] Weaker patents might not bother these industries, and they

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[233] *Id*. at 1113.

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

[235] *E.g.*, Gene Quinn, *A Patent Eligibility in Crisis: A Conversation with Bob Stoll*, IPWATCHDOG (Oct. 10, 2014) (quoting Bob Stoll, former Commissioner for patents at the USPTO) (arguing against recent court decisions that weaken patents and stating that courts "seem to be not considering the fact that the United States is leading in many [technologies where patents are being weakened]" and that "you're going to start to see some of these companies . . . start to move to other jurisdictions, . . . you're going to see jobs leaving the United States and research going overseas" because of weaker patents); Frank Cullen, *Why We Shouldn't Go Soft on Software Protection*, The Global Intellectual Property 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.").

[236] *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 startup companies indicating that software

might even gain competitiveness. Indeed some industry actors actively seek a weaker patent system.[237]

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 be felt more by domestic businesses than by foreign ones. William Hubbard has pointed out that the majority of U.S. patents are issued to foreign inventors, and thus any increase in the value of U.S. patents will disproportionately benefit non-U.S. inventors.[238] As a corollary, therefore, any decrease in the value of U.S. patents will actually tend to affect foreign inventors more than U.S. inventors.[239]

Moreover, analyses of global competitiveness must account for the fact that strong patents reduce *domestic* rivalry among U.S. companies. In a separate article, Professor Hubbard demonstrates that U.S. policymakers have failed to account for the patent system's reduction in domestic rivalry.[240] U.S. patents insulate U.S. companies from domestic competition, but intense domestic rivalry tends to increase a country's global competitiveness.[241] In essence, domestic rivalry acts as a sort of

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).

[237] *See, e.g.*, FED. TRADE COMM'N, TO PROMOTE INNOVATION: THE PROPER BALANCE OF COMPETITION AND PATENT LAW AND POLICY, ch. 3, at 43 ("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.

[238] *See* 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 U.S. businesses might enjoy disproportionate effects of stronger patents if the U.S. patents obtained by U.S. inventors are more commercially valuable. *Id*. at 373, n.220.

[239] Hubbard's observations also counsel for further research on the United State's inventive profile compared to other countries. Specifically, suppose that the bulk of U.S. 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 U.S. as compared to its inventive rivals. Cf. *id*. at 375-78 (analyzing ways to selectively strengthen U.S. patents in a way that disproportionately affects U.S. businesses). To study this, future researchers would need to look not simply at the number of patents in each technology sector, but the value of those patents.

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

[241] *Id*. at 1913, 1936-38, 1942-44.

training ground that prepares business for global competition. Thus, weakening U.S. patents will increase domestic rivalry among U.S. 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.[242]

Hubbard's insights align with intuition and psychological insights.[243] 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 our proposal to weaken patents and provides an independent variable favoring weakening patents.[244]

Of course, Hubbard's observations used a static model of inventor location; that is, it assumed that inventors (typically businesses) would not relocate to different countries seeking stronger patents or less intense competition.[245] Thus, one must consider the strength of the argument that businesses will leave the U.S. in response to weaker patents.

We recognize the potential for relocation responses, but are of the opinion 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(s) decisions, including, but are not limited to, proximity to highly skilled workers, supporting industries, and low production and/or distribution costs, favorable regulatory environments, and the personal desires of the

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[242] *Id*. at 1913.

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

[244] 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 patnets 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 U.S. trade surplus in intellectual property of $82 billion). The reduction should be offset by competitiveness gains.

[245] In his *Competitive Patent Law* article, Professor Hubbard was considering ways to *strengthen*, not weaken, U.S. patents in ways that benefitted the U.S. *See* Hubbard, *Competitive Patent Law*, *supra* note 238. Thus, any movement of businesses would have tended to be *into* the U.S.

company's leadership.[246] These and other factors are highly dependent on the specific company and industry. We observe, however that regarding highly skilled workers, the U.S. ranks seventh in the 2014-15 World Economic Forum's ranking for Higher Education and Training.[247] In addition, the U.S. ranks seventh in the most recent World Bank "ease of doing business" ranking, suggesting a favorable regulatory environment.[248] Finally, regarding a company's location(s), we note that the U.S. is a particularly fertile ground for startups, suggesting that many new, innovative companies will begin in the U.S.[249]

Furthermore, even if lawmakers weaken patents, companies will continue to be drawn to the United States because it represents the world's top consumer market.[250] Many companies will need offices in the U.S. to adequately serve this large consumer market and thus are unlikely to flee en mass. 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 we advocate weakening, but not abolishing, patents, the U.S. market will continue to provide opportunities for patent-boosted pricing. The patent system will thus continue incentivizing companies to maintain a presence in the U.S. even assuming the net effects of our proposed changes are negative for certain companies.

4. Additional Considerations

Besides the three highly important points of attention discussed above, policymakers will need to weigh numerous other considerations.

[246] *See, e.g.*, MICHAEL PORTER, THE COMPETITIVE ADVANTAGE OF NATIONS 77 (1990) (indicating that high skilled labor is important for competitive advantage); *id*. at 138-40 (discussing supporting industries)

[247] WORLD ECONOMIC FORUM, GLOBAL COMPETITIVENESS REPORT 2014-2015 19, *available at* http://www3.weforum.org/docs/WEF_GlobalCompetitivenessReport_2014-15.pdf.

[248] *Ease of Doing Business Index*, THE 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.

[249] Rip Empson, *Startup Genome Ranks The World's Top Startup Ecosystems: Silicon Valley, Tel Aviv & L.A. Lead The Way*, TECHCRUNCH (Nov. 20, 2012) (noting that five of the top six cities in a recent ranking of top cities for startups were in the U.S.). Of course, the strength of the current patent system may be a contributor to this state of affairs.

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

For example, weakening the patent system will, all else equal, tend to cause inventions to occur at a later time, which will make the inventions fall into the public domain later.[251] 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 are available more often in today's technological environment than in year's 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 25%-50%, we now turn 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.[252] Though there are many choices for such changes, we explore three here. First, we explore shortening the patent term. Second, we explore increasing maintenance fees. Finally, we explore a variety of doctrinal changes that, while facially neutral, clearly target certain technologies.

1. <u>Shortening the Patent Term</u>

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 how to film a yoga class[253] all generally receive the same twenty-year term[254] and

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[251] Duffy, *supra* note 206.

[252] 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. *Cf*. Leahy-Smith America Invents Act § 14 (2011) (excluding tax strategies from patent protection). We believe that 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 710-711.

[253] Filming a Yoga Class, U.S. Patent No. 8,605,152 (filed Feb. 8, 2013).

[254] We recognize that maintenance fee requirements establish a de facto differentiation in patent term and we discuss this below in Part III.B.2. The twenty-year term is granted in 35 U.S.C. § 154(a)(2). Patent terms can be adjusted for various delays,

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.[255] Weakening patents through uniform changes to patent laws can avoid many of the difficulties of tailored reform.[256]

To weaken patents by 25%-50%, 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*.[257] However, after a patent is filed the patent office examines it, and on average a patent will take about three years before it issues.[258] Thus, the average life of an issued patent is about seventeen years.[259] 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.[260] According to the incentive-to-invent and incentive-to-

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the most significant of which is that extensions for pharmaceuticals based on delays involved in obtaining regulatory approval. *See* 35 U.S.C. § 156 (2015). Other extensions are for delays at the patent office. *See* 35 U.S.C. § 154(b) (2015).

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

[256] Uniform changes are, in one sense, technology neutral in that the law applies equally to all patents regardless of technology. *See id.* at 704 (referring to uniform changes as technology-neutral). But 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).

[257] More accurately, from its earliest priority date. 35 U.S.C. § 154(a)(2) (2015).

[258] 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.

[259] Patent owners cannot file infringement suits until the patent issues. *See* 35 U.S.C. § 271 (2015). 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. *Id*. at § 154(d).

[260] 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 50% decrease in patent term would not necessarily decrease the value of the patent to its

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.[261] Further, increasing the technological commons would beneficially increase the rate at which innovations could build on earlier innovations, potentially increasing the rate of innovation.[262]

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,[263] commentators repeatedly lament the inability to obtain the proper data to analyze the effects of uniform changes to patent laws.[264] Our 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 others who analyze the patent system, we

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owner by half. For example, the useful life of the technology might have been shorter than the twenty year patent term.

[261] *Id*. at 66-67. 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 long time. Duffy, *supra* note 206, at 493-98; John F. Duffy, *A Minimal Optimal Patent Term*, 1, 3 (unpublished manuscript 2004), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=354282.

[262] *See, e.g.*, Roin, *supra* note 14, at 694-97.

[263] *E.g.*, WILLIAM D. NORDHAUS, INVENTION, GROWTH, AND WELFARE: A THEORETICAL TREATMENT OF TECHNOLOGICAL CHANGE (1969); Michael Abramowicz, *Orphan Business Models: Toward a New Form of Intellectual Property*, 124 HARV. L. REV. 1362, 1396-1420 (2011); 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, 269 (2006); Khoury, *supra* note 14, at 374; Peter S. Menell, *A Method for Reforming the Patent System*, 13 MICH. TELECOMM. & TECH. L. REV. 487, 493 (2007).

[264] *See, e.g.*, Roin, *supra* note 14, at 704-05.

cannot "prove" this assertion empirically. We do not find evidence that any other key variables of the innovation calculus have changed with any magnitude so as to counteract the decreased rate 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, we believe its effects are minimal when the patent system is only weakened between 25%-50%. 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 freely licensed to all innovators, follow-on innovation would only be impeded by the costs of those license rates. Certain technologies, most notably the internet, have reduced costs of finding relevant patents and communicating with patent owners, and standards setting organizations in some cases improve licensing.[265] But we do not find any suggestion in the literature that transaction costs have decreased in any fundamental way.[266]

We note also that patents can be weakened by changing their breadth,[267] and that recent Supreme Court decisions appear to have weakened patents to some extent.[268] Further, recent legislative changes to the patent system may, in some cases, weaken patents. To the extent that court decisions or legislative changes have already weakened patents to some extent, the length by which the patent term should be shortened would decrease. We do not believe, however, that the recent changes are

[265] Mark A. Lemley, *Intellectual Property Rights and Standard-Setting Organizations*, 90 CAL. L. REV. 1889 (2002).

[266] *Cf.* 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 (cataloguing 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, at 368-69 (reviewing transaction costs that can stifle commercialization).

[267] Gilbert & Shapiro construct an economic model that suggests as between length and breadth, changing patent breadth is the better policy lever. Gilbert & Shapiro, *supra* note 263, at 106-11. As the authors admit, this model ignores the cumulative nature of innovation. *Id.* at 112.

[268] *See infra* note 298 (listing cases).

likely to have a profound impact on the patent system on the level that we propose.[269]

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 (TRIPS).[270] The TRIPS agreement requires the patent term to be at least twenty years from the filing date.[271] In addition to being politically embarrassing to violate a treaty that the United States pushed for vigorously,[272] any violation of the agreement would allow other countries to complain and possibly institute retaliatory trade measures.[273] 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 suggests that it would be extremely difficult to push through a change in the patent term. Specifically, while some industries, such as software, might welcome the change, other industries, most notably the biotechnology and pharmaceutical industries would fiercely oppose it.[274] Historically, the biopharma industry lobby has prevented major changes to the patent system that might weaken patents.[275] This suggests that shortening the patent term would be an

[269] The one exception to this may be the decision in Alice Corp. Pty. Ltd. v. CLS Bank Int'l, 134 S. Ct. 2347 (2014). 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), http://www.slate.com/articles/technology/future_tense/2014/06/alice_v_cls_bank_supreme_court_gets_software_patent_ruling_right.html (contending that the decision "significantly tighten[ed] the standard for what is and what is not patentable").

[270] Agreement on Trade-Related Aspects of Intellectual Property Rights, Apr. 15, 1994, Marrakesh Agreement Establishing the World Trade Organization, Annex 1C, 1869 U.N.T.S. 299 (1994).

[271] *Id*. at Art. 33.

[272] *See* DANIEL GERVAIS, THE TRIPS AGREEMENT: DRAFTING HISTORY & ANALYSIS 11-27 (3d ed. 2008) (documenting the negotiation history of the TRIPS agreement).

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

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

[275] *See, e.g.*, Roin, *supra* note 14, at 679-81.

incredibly difficult endeavor unless lawmakers gave a carve-out to the biopharma sector.[276]

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).[277] Several commentators have analyzed maintenance fees, particularly as a deterrent to non-practicing entities (also called patent trolls).[278] As their name implies, maintenance fees are fees that must be paid to keep a patent enforce. Fees must be paid by 3.5, 7.5, and 11.5 years after the patent is granted.[279] If the fees are not paid, the patent will expire.[280] Currently, maintenance fees are $1,600, $3,600, and $7,400 respectively for 3.5, 7.5, and 11.5 years.[281]

[276] Providing an appropriate carve-out carries its own line-drawing and political economy issues. *See* Rai, *supra* note 256, at 1040 (noting that a patent law carve-out for a given industry may be hard to define and apply).

[277] 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).

[278] 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) (recommending that "renewal fees should rise much more with patent length than existing fee schedules"); Love, *supra* note 277; 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 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*, http://ssrn.com/abstract=2318521.

[279] 35 U.S.C. 41 (b). 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).

[280] *Id*. The patentee may be excused for late payment if the tardiness was "unavoidable." *Id*. § 41(c).

[281] *See* USPTO Fee Schedule, USPTO (Jan. 17, 2015), http://www.uspto.gov/learning-and-resources/fees-and-payment/uspto-fee-schedule. 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 Office for processing, activities, services, and materials relating to patents." Leahy-Smith America Invents Act § 10; 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/laws-and-

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 not to pay the maintenance fee. Indeed, studies show that about 50% of issued patents expire prematurely for failure to pay maintenance fees.[282]

To weaken patents by 25%-50%, the patent office could raise some maintenance fees substantially and/or increase the frequency with which they are required.[283] 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 or it could raise all of them. 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. Thus, for example, to achieve something close to our proposed 25%-50% 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).

Once 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. This concern is alleviated by our suggestion not to begin raising fees until at least the second fee.

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 50% fee reductions for "small" entities (generally universities, non-profits, and businesses with fewer than 500 employees)[284] and 75% 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 three

regulations/america-invents-act-aia/fees-and-budgetary-issues (last visited Feb. 20, 2015).

[282] Moore, *supra* note 278, at 1526; Dennis Crouch, *Paying Maintenance Fees*, PATENTLY-O (Sept. 26, 2012), http://patentlyo.com/patent/2012/09/patent-maintenance-fees.html.

[283] We lack the data to know what magnitude of increase would mimic a 50% reduction in patent term. It might be on the order of a ten-fold or one-hundred-fold increase, if not more.

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

times the median household income).[285] We propose to maintain reduced fees for small and micro entities.

Although significantly increasing maintenance fees will have similar impacts to reducing the patent term, we expect political opposition to this approach from the biopharma sector to be less intense compared to shortening the patent term. Our prediction is based on the realities of invention and commercial success in biopharma. Specifically, an "overwhelming number of drugs that enter clinical trials don't actually get approved by the FDA, so drug makers try to recover those costs when they have a successful product."[286] 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.[287] 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.

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.[288] And 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.[289] Empirical research supports this analysis.[290]

Raising maintenance fees would likely have other beneficial effects. Most obviously, it would increase the commons (i.e., the

[285] 35 U.S.C. § 123 (2015).

[286] Jason Millman, *Does it Really Cost $2.6 Billion to Develop a New Drug?*, Washington 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/.

[287] Sarah E. Eurek, Note, *Hatch–Waxman Reform and Accelerated Market Entry of Generic Drugs: Is Faster Necessarily Better?*, 2 DUKE L. & TECH. REV. 18, 20 (2003) (noting that the high cost of drug development "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.").

[288] *Cf.* Olson, *supra* note 278, at 37 (noting that biopharma companies tend to have smaller patent portfolios).

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

[290] Moore, *supra* note 278, at 1543-44, 1547-48.

technology in the public domain).[291] Further, economic research suggests it could increase social welfare.[292] Perhaps most importantly, it would tend to lessen the problem of non-practicing entities (patent trolls) by significantly raising their operating costs, especially since non-practicing entities tend to assert patents that are coming to the end of the twenty-year term.[293] 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).[294] David Olson chronicles the problems with patent thickets in detail and recommends using maintenance fees to alleviate the problem.[295]

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.[296] 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 backs this up.[297] Under our

[291] Admittedly only less valuable inventions would expire.

[292] Cornelli & Schankerman, *supra* note 278, at 197 (finding that raising maintenance fees more sharply for high R&D productivity firms would yield significant welfare gains).

[293] Chien, *supra* note 278, at 360-63 (2012) (discussing an increase in maintenance fees as a deterrent to non-practicing entity patent litigation); Love, *supra* note 277, 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 278, at 1836-37 (2007) (noting that maintenance fee increases could help battle patent trolls); Olson, *supra* note 278, at 2-10.

[294] Olson, *supra* note 278, at 2-10.

[295] *Id*. at 2-10, 22-30.

[296] Dennis Crouch, *USPTO Maintenance Fees*, PATENTLY-O (Feb. 20, 2012) ("Over half of the USPTO operational budget is derived from maintenance (or renewal) fees paid by patentees.").

[297] 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 (2013) (noting that the patent office, because it is funded largely by post-filing fees, will be tempted to grant more patents in an effort to ensure a continued stream of

proposal, the patent office may be averse to increasing later stage maintenance fees if it will decrease its revenue.

Even if it is willing to change its fees according to our 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 early stage maintenance fees. It is possible that these two temptations will offset each other, resulting in a more socially optimal patent issuance rate.

3. Semi-Selective 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 medical-related inventions.[298] As discussed previously, the Supreme Court's decision in *Alice Corp. Pty. Ltd. v. CLS Bank Int'l* is believed by many to significantly weaken software patents.[299]

Extending such semi-targeted approaches to other technologies could decrease the incentives to innovate in line with our recommendation. But the way forward is complex. For example, how

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 STUDIES 602 (2014) (noting that the patent office, because it is funded largely by post-filing fees, will be tempted extend preferential examination treatment to simple technologies that are inexpensive to process).

[298] Regarding software patents, see Nautilus, Inc. v. Biosig Instruments, Inc., 134 S. Ct. 2120 (2014) (raising the standard for definiteness in patent claims); Alice Corp. Pty. Ltd. v. CLS Bank Int'l, 134 S. Ct. 2347 (2014) (arguably raising the standard for patentable subject matter). For medical-related patents, see Ass'n for Molecular Pathology v. Myriad Genetics, Inc., 133 S. Ct. 2107 (2013) (arguably raising the standard for patentable subject matter); Mayo Collaborative Servs. v. Prometheus Labs., Inc., 132 S. Ct. 1289 (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. 1727 (2007) (making more would-be inventions obvious); eBay Inc. v. MercExchange, L.L.C., 547 U.S. 388 (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.

[299] *See supra* note 269.

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, it is the products that can be printed by 3D printers whose innovation costs are lowered most substantially. These products can be digitized in CAD programs and shared and manipulated in digital form.

So, to weaken 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.[300] If CAD files were not protected by patents, individuals would be free to create, share, and even perhaps sell CAD files that would print the patented physical devices.[301] It may that *Alice* will preclude patent protection for CAD files.[302]

Even if Alice precludes patents for CAD files, however, the solution is not perfect because printing the physical device would constitute infringement as a "making" of the patented invention.[303] Thus, individuals and businesses that print the items could be liable as infringers.[304] True, it would be difficult in some cases for the patent owner to detect infringement, such as where it is done in the privacy of a home or business for individualized use.[305] But the fact of infringement 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.

Moreover, owners of the patents to the physical device could bring claims for inducing infringement and contributory infringement.[306] For example, a CAD file creator or distributor could be liable for inducing infringement if it sent the file to another with the intent that the recipient

[300] *See* Timothy R. Holbrook & Lucas S. Osborn, *Digital Patent Infringement in an Era of 3D Printing*, 48 U.C. DAVIS L. REV. ___ (forthcoming 2015).

[301] *Id*.

[302] *Id*. *But see* Daniel Harris Brean, *Patenting Physibles: A Fresh Perspective for Claiming 3D-Printable Products*, -- SANTA CLARA L. REV. --- (forthcoming 2015) (arguing that CAD files can be patented).

[303] 35 U.S.C. § 271(a) (2015); Holbrook & Osborn, *supra* note 300, at 44.

[304] Holbrook & Osborn, *supra* note 300, at 44.

[305] *Id*.

[306] *Id*. at 12-32. Inducing infringement is actionable under 35 U.S.C. § 271(b), and contributory infringement is actionable under § 271(c).

print it.[307] This would discourage dissemination of the patented technology, especially for important facilitators of 3D printing technology like CAD file hosting sites.[308]

A significant limitation for allegations of indirect infringement, however, is that the alleged infringer must intend to infringe.[309] At a minimum this requires knowledge of the patent (or willful blindness).[310] Many actors, particularly laypersons, will be unaware of any patent and thus will not evince the requisite intent.[311] For intermediaries like CAD file hosting sites, though, patentees will send notice letters informing the intermediary of their patent and demanding that the intermediary remove the file. Thus, potential claims for indirect infringement will yield continued patent power over technologies directly affected by 3D printing.

In addition, as one of us pointed out in another article, patent owners of patents with claims covering physical devices (but not claims covering CAD files of the devices) might successfully assert *direct* infringement claims against CAD file makers, distributors, and sellers on the basis of the CAD file alone.[312] Claims of direct infringement are much more dangerous for the accused infringer because direct infringement is a strict liability offense—it does not require knowledge of the patent or intent to infringe.[313] To the extent that courts recognize acts of such "digital" infringement, patent protection for technologies directly affected by 3D printing will continue to be strong.

Although doctrinal tweaks to patent laws do not necessarily weaken patents as much as we recommend, they are not without benefits. Most importantly, they are relatively narrowly tailored to specific technologies. This 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

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[307] Holbrook & Osborn, *supra* note 300, at 15-20.
[308] *Id*.
[309] *Id*.
[310] *Id*.
[311] *Id*.
[312] *Id*. at 33-48.
[313] *Id*.

of doctrinal reform is that the courts can accomplish it, thus bypassing the interest group wrangling that has stymied other reforms.[314]

In sum, doctrinal changes to the laws have the potential to be more targeted, but less stringent than changes to the patent term or maintenance fees. Because we think doctrinal changes involve too much uncertainty, we consider them a second-best option, albeit a good one.

IV. 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, 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 demonstrate that now is the time for significant patent reform. Lawyers, typically, are a cautious lot. But a new age of innovation promises rapid and collaborative technological progress. Experimentation and change, not caution, are called for.

[314] Some may understandable argue that bypassing democratic debate is not a benefit. As used here we use "benefit" narrowly to mean that doctrinal tweaks accomplish our goal.