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Patents and Technology Evolution: Altering Innovations and Innovators via Patent Influences

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ABSTRACT

Technologies improve primarily through evolutionary change not rational optimization. New technologies emerge as attempts to solve practical problems, the technologies are tested in marketplaces to determine if they are superior in cost and function to alternatives, and those that fare well in the testing gain widespread adoption. Widely adopted technologies, and their problems, form the basis for the next round of technology improvements and evolution. Through these steps, evolutionary processes lacking rational direction can generate changing technologies matched to the desires and problems of present society.

As they operate to advance diverse technologies, evolutionary processes governing technology change are subject to important influences from patent rights and incentives. Patent interests affect how new inventions that are outliers departing materially from prevailing knowledge in their technical fields are generated, tested, and propagated. Patent rewards also increase the strength of innovators who are successful in producing outlier advances, enhancing the chances that these parties can generate more outlier inventions. By biasing technology change processes towards more outlier inventions, more marketplace testing of those inventions, and greater strength of innovators capable of creating outlier inventions, the patent system enhances technology change through evolution in several respects and broadens the

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range of useful advances made available to the public. This article describes these important patent influences on technology evolution. It also includes a normative discussion of changes in patent laws that will increase the impacts of patents on outlier innovations and the diversity of useful advances made available to the public.

I. Evolution: A General Framework for Change

A. Freeing Evolution from the Confines of the Gene

Evolution[1] is a general mechanism for change, not just a biological process.[2] While the particular example of biological evolution has gained the most attention, evolution has much broader impacts on ideas and artifacts.[3] Some analysts contend that evolutionary change underlies changes in all types of complex systems[4] although the particular mechanisms for change within evolutionary frameworks are different in different contexts.[5] If the characteristics of ideal systems are static, evolutionary change may provide a route to incrementally alter complex systems towards ever better approximations of ideal features. However, where, as with most social systems, public needs and preferences are changing, evolutionary alterations

[1] The term "evolution" is sometimes loosely used to indicate "gradual change." *See, e.g.,* James E. Krier, *Evolutionary Theory and the Origin of Property Rights*, 95 CORNELL L. REV. 139, 145 (2009). This is not the meaning adopted here. In this article, "evolution" will refer to processes involving item feature variation, inheritance, and selection with parallels to the mechanisms of biological evolution first recognized by Charles Darwin. *See,* Geoffrey M. Hodgson & Thorbjørn Knudsen, *Why we need a generalized Darwinism, and why generalized Darwinism is not enough*, 61 J. OF ECON. BEHAVIOR & ORG. 1, 1-3 (2006).

[2] In contrast to the view that evolution as recognized by Charles Darwin is a process restricted to biological change, Darwin himself saw evolutionary change as having much greater impacts. For example, Darwin noted that evolutionary change may have accounted for features of language development and changes in concepts of morality. C. R. Darwin, THE DESCENT OF MAN, AND SELECTION IN RELATION, vol. 1 at 59-61, 106, 16 (1871); C. R. Darwin, ON THE ORIGIN OF SPECIES 422-23 (1859). *See also* Geoffrey M. Hodgson & Thorbjørn Knudsen, *Why we need a generalized Darwinism, and why generalized Darwinism is not enough*, 61 J. OF ECON. BEHAVIOR & ORG. 1, 4-5 (2006); Deaniel C. Dennett, DARWIN'S DANGEROUS IDEA 48-60 (1995) (observing that Darwin's ideas described evolutionary algorithms that can be "lifted out of their home base in biology" to assess other types of change processes).

[3] *See* Geoffrey M. Hodgson & Thorbjørn Knudsen, *Why we need a generalized Darwinism, and why generalized Darwinism is not enough*, 61 J. OF ECON. BEHAVIOR & ORG. 1, 4-5 (2006) (noting the use of evolutionary principles to explain changes in diverse social features ranging from business firms to individual habits, customs, rules and routines).

[4] Richard Dawkins contends that evolution -- not limited to biological evolution alone -- accounts for essential features of modern man:

> [F]or an understanding of the evolution of modern man, we must begin by throwing out the gene as the sole basis of our ideas on evolution. … Darwinism is too big a theory to be confined to the narrow context of the gene.
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> …
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> We biologists have assimilated the idea of genetic evolution so deeply that we tend to forget that it is only one of many kinds of evolution.

Richard Dawkins, THE SELFISH GENE 191-94 (1976).

[5] Geoffrey M. Hodgson & Thorbjørn Knudsen, *Why we need a generalized Darwinism, and why generalized Darwinism is not enough*, 61 J. OF ECON. BEHAVIOR & ORG. 1, 16-17 (2006).

may necessarily be imperfect as changes are driven by past preferences and are somewhat out of sync with today's preferences and public wishes.[6]

B. Evolution Applied to Technology Development

Technology development is one of many societal features shaped through evolutionary processes.[7] Technology changes emerge from repeated cycles of evolution involving the variation of technology designs through inventions, selection of designs with superior functionality through testing in marketplaces leading to widespread propagation of designs that fare well in this testing, and inheritance of features of successful designs in future change cycles via reliance on previously successful designs as the basis for additional rounds of improvements and changes. Repetitions of these evolutionary cycles have increased the functionality of applications and devices as new knowledge or design approaches have enabled new technology features. At the same time, evolutionary change has ensured that the focus of new technology development has tracked changing societal needs and tastes.

C. The Undirected Power of Technology Evolution

Technology evolution achieves technology change and improvement without a guiding hand or single source of innovation targeting or development.[8] Variation, testing, and

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[6] Richard R. Nelson and Sidney G. Winter have made this same point in the context of evolutionary changes defining business behaviors:

> If the analysis concerns a hypothetical static economy, where the underlying economic problem is standing still, it is reasonable to ask whether the dynamics of an evolutionary selection process can [cause surviving firms to adopt practices maximizing business returns] in the long run. But if the economy is undergoing continuing exogenous change, and particularly if it is changing in unanticipated ways, then there really is no "long run" in a substantive sense. Rather, the selection process is always in a transient phase, groping toward its temporary target. In that case, we should expect to find firm behavior always maladapted to its current environment and in characteristic ways — for example, out of date because of learning and adjustment lags, or "unstable" because of ongoing experimentation and trial-and-error learning.

Richard R. Nelson & Sidney G. Winter, *Evolutionary Theorizing in Economics*, 16 J. OF ECON. PERSPECTIVES 23, 26 (2002).

[7] Analyzing technology development through an evolutionary lens provides a powerful means to understand both the impacts of technology changes on society and the impacts of social features on technology advancement. As recognized by noted technology scholar Henry Petroski:

> Putting implements as common as a knife and fork and chopsticks into an evolutionary perspective … gives a new slant to the concept of their design, for they do not spring fully formed from the mind of some maker but, rather, become shaped and reshaped through the (principally negative) experiences of their users within the social, cultural, and technological contexts in which they are embedded. The formal evolution of artifacts in turn has profound influences on how we use them.

Henry Petroski, THE EVOLUTION OF USEFUL THINGS 19-20 (1992).

[8] *Cf.* Richard Dawkins, THE BLIND WATCHMAKER: WHY THE EVIDENCE OF EVOLUTION REVEALS A UNIVERSE WITHOUT DESIGN (1986) (arguing that complexity in nature results from unguided natural selection, realizing over time complex biological features).

propagation are primarily private processes proceeding in multiple sites, often in competition with each other. Commercial pressures (some usefully augmented by patent incentives as will be described at a later point in this article) tend to tie innovation targets to public desires and needs. User demand informs innovators' attempts to fill that demand, focusing intense innovation efforts on applications with widespread uses and associated commercial potential. Through repeated cycles of technological innovation and testing, remarkably complex technological tools have been developed to meet diverse user needs without the involvement of conscious control of the overall design process.[9]

D. Patent Influences Biasing Technology Evolution to Favor Outliers

Patents influence technology development by manipulating features of technology evolution.[10] Patents bias technology development processes to favor advances with outlier designs departing from conventional technology designs and knowledge. By doing so, patents implement a form of artificial, directed evolution aimed at enhancing technology change. In parallel processes involving living organisms, directed evolution techniques bias evolutionary processes towards rapidly producing desirable changes in organism features and functions.[11] Patents have similar impacts on evolutionary processes governing technology improvements. By biasing technology development towards greater production of outlier technologies and differentially promoting the testing and propagation of those outlier technologies, patents can help highlight outlier technologies in technology change and move technology developments quickly towards public benefits achieved through fundamentally new design solutions. Interpreting patents as agents of directed technology evolution can help us understand the current impacts of patents on technology change and reveal reforms in patent standards and practices that can improve technology development to the benefit of technology users.

Patents impact technology evolution in at least three ways. First, the promise of patent rewards for advances with non-obvious designs (diverging materially from past technology understanding in the relevant fields) ensures that increased numbers of design outliers and departures are created.[12] Innovations departing from conventional thinking are specially rewarded and encouraged, biasing creative processes towards outliers and resulting in an expanded range of technology solutions developed to address particular practical problems. Second, patent rights providing marketplace exclusivity ensure that patented designs are given special attention by parties interested in commercializing and distributing new technologies.[13] This heightened attention promotes market testing of advances with outlier designs. Third, technology designers that succeed in producing outlier advances with significant utility and

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[9] *See, e.g.,* Peter Bentley, *An Introduction to Evolutionary Design by Computers* in EVOLUTIONARY DESIGN BY COMPUTERS 1, 5-8 (Peter Bentley ed. 1999) (noting the ability of evolutionary design of computer software technology to generate highly innovative and complex designs for serving user needs).
[10] The mechanisms of patent influence on technology evolution are described in detail in Section III, *infra*.
[11] *See* Section II(B)(3), *infra*.
[12] *See* Section III(B), *infra*.
[13] *See* Section III(C), *infra*.

widespread use can gain large patent-influenced rewards which will strengthen the subsequent research efforts of these successful innovators.[14] Patent-induced support can ensure that technologists with proven success in generating technology outliers have opportunities and resources to innovate again and produce more outlier advances for future testing and potential adoption.

This article presents descriptive and normative accounts of patent influences on technology evolution. It describes how patent rights and incentives promote the development and market testing of outlier advances broadening the range of potentially valuable technologies serving public needs. The article also analyzes potential levers of patent influence on technology evolution and the ways that improvements in patent laws and practices can better promote technology evolution and the development of useful technologies available for widespread public adoption and benefit.

II. Understanding Technology Evolution

A. Frameworks Drawn from Biological Evolution

Charles Darwin's theory of natural selection in biologic settings provides foundational concepts for understanding technological evolution.[15] Just as organisms change through variation, selection, and retention in biological evolution, technologies evolve[16] through

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[14] *See* Section III(D), *infra*.

[15] The range of human artifacts constituting "technology" and subject to changes via "technology evolution" is very broad. Technology includes any artificial (that is, human created) "means to fulfill a purpose." W. Brian Arthur & Wolfgang Polak, *The Evolution of Technology within a Simple Computer Model*, Santa Fe Institute Working Paper 2004-12-042 at 1 (Dec. 17, 2004), https://sfi-edu.s3.amazonaws.com/sfi-edu/production/uploads/sfi-com/dev/uploads/filer/25/61/25617f0e-394e-4a2c-9f60-0dedc2557d82/04-12-042.pdf. Artifacts constituting technology within this definition include such diverse creations and constructs as physical devices, methods, industrial processes, and algorithms. *Id.* Changes in these different artifacts proceed via evolution "driven by human needs and by needs created by other technologies." *Id.*

[16] Analyzing changes in biological organisms and technological items in parallel evolutionary terms assesses both types of changes within "meta-theoretical frameworks" reflecting higher level evolutionary principles and constraints. Mario Coccia, *The theory of technological parasitism for the measurement of the evolution of technology and technological forecasting*, 141 TECH. FORECASTING & SOCIAL CHANGE 289, 290 (2019). These accounts recognize that the evolutionary patterns first recorded by Charles Darwin in biological settings reflect, at bottom, more generally applicable change algorithms through which designs of items are gradually modified to respond to features of surrounding environments. These algorithms can explain patterns of change in diverse contexts from biological organisms to technological artifacts. *See* Deaniel C. Dennett, DARWIN'S DANGEROUS IDEA 48-60 (1995); John Ziman, *Evolutionary Models for Technological Change* in TECHNOLOGICAL INNOVATION AS AN EVOLUTIONARY PROCESS 3, 11 (J. Ziman ed. 2000) (noting that biological and technological systems might best be viewed as "distinct members of a larger genus of *complex systems*" that change through a selectionist paradigm described by Darwin in biological systems).

Accounts of technology evolution are part of broader efforts to use evolutionary algorithms to describe cultural changes. Richard Dawkins, in his path breaking text "The Selfish Gene," describes cultural evolution in terms of "memes" or units of cultural transmission. Richard Dawkins, THE SELFISH GENE 206 (1976). Dawkin's concept of cultural memes included technology features such as "ways of making pots or of building arches." *Id.* He contended these sorts of memes (including technology details) evolved through propagation via communication among parties, competition among memes to achieve popularity among the public (based on various criteria variation in new innovations, selection through market testing of innovations for matches to societal needs and desires, and retention via institutional support and standardization of innovations broadly embraced by the public.[17] These processes drive technological development, tending to ensure that only the most effective and useful technologies persist over time.[18]

Evolutionary accounts of changes in such diverse things as living organisms and useful technologies are possible because evolution is a generally applicable process for change that can be applied to mediate and potentially increase changes in a wide variety of settings.[19] In its most abstract form, evolution is a structured system of trial and error conducted over multiple cycles with gains achieved in one cycle carried over to the next.[20] A "trial" is a variation from prior practice or situation. An "error" is a poorer result (or perceived poorer result) achieved in a given cycle than achieved by unvaried counterparts. Between cycles, relatively successful versions (either the varied or unvaried versions) are selected and allowed to proceed to the next cycle while the less successful alternatives are eliminated. Repeated applications of this last selection step in biological settings accounts for the shorthand label of evolution as tending towards "survival of the fittest."

This section describes evolutionary mechanisms producing changes in technology designs. It focuses first on biological evolution as a well-studied precursor to technology

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leading to popularity), and repropagation of the winning, popular memes to form the platform for further cultural processes. *See id.* at 212; *see also* Deaniel C. Dennett, DARWIN'S DANGEROUS IDEA 342-52 (1995). Technology evolution can be seen as versions of meme evolution, with the selection of successful technical design memes achieved primarily through market testing and consumer preferences. *See, e.g.,* Derek Gatherer, *The Memetics of Design* in EVOLUTIONARY DESIGN BY COMPUTERS 91, 92-93 (Peter Bentley ed. 1999).

[17] The view that technological change proceeds through evolutionary processes has been recognized for some time. Several analysts in different disciplines independently reached this conclusion as early as the mid-1970s. *See* Richard R. Nelson & Sidney G. Winter, *Evolutionary Theorizing in Economics* 16 J. OF ECON. PERSPECTIVES 23, 38 (2002). *See also* John Ziman, *Evolutionary Models for Technological Change* in TECHNOLOGICAL INNOVATION AS AN EVOLUTIONARY PROCESS 3, 3 (J. Ziman ed. 2000) (noting that "the basic analogy between biological and cultural evolution [including technological evolution] has often been remarked.").

[18] Other types of useful constructs may change and survive via evolutionary processes with variation and selection steps similar to those found in biological evolution. *Cf.* R. R. Nelson & S. G. Winter, AN EVOLUTIONARY THEORY OF ECONOMIC CHANGE (1982) (arguing that behaviors of business firms change and survive in evolutionary patterns similar to those in biological evolution).

[19] In their most abstract terms, evolutionary search algorithms define steps to search for solutions to any type of problem. *See, e.g.,* Peter Bentley, *An Introduction to Evolutionary Design by Computers* in EVOLUTIONARY DESIGN BY COMPUTERS 1, 5-8 (Peter Bentley ed. 1999).

[20] In its various forms – from biological evolution to technological evolution – evolution can be conceived as a search (sometimes largely unguided and proceeding through only partially understood variations of alternatives) for improvements over present circumstances:

> Technological evolution, like biological evolution, can be considered a search across a space of possibilities on complex, multipeaked "fitness," "efficiency," or "cost" landscapes.

S. Kauffman & W. Macready, *Technological evolution and adaptive organizations: ideas from biology may find applications in economics*. 1 COMPLEXITY 26, 26 (1995), https://doi.org/10.1002/cplx.6130010208.

evolution. Studies of biological evolution have identified more general principles of evolution that can be applied to analyze and direct evolutionary mechanisms in fields divorced from biological change. The results of these studies – and the recent success of methods to manipulate biological evolution – provide insights that are also useful in understanding technology evolution.

With this introduction based on biological evolution, the section goes on to provide a detailed account of the elements of technology evolution along with some examples of technology designs developed through evolutionary mechanisms.

Section III of this article will extend this discussion to analyze the impacts of patent rights and rewards on features of technology evolution and the potential of patent-enhanced evolutionary processes to expand the range of useful technologies brought to public access.

B. Early Recognition of Evolution in Nature

1. Darwinian Evolution: Understanding the Essential Features of Evolutionary Change in Biological Settings

Studies of evolutionary change in nature – building on Charles Darwin's path breaking work – have identified several essential steps in biological evolution. These steps involve variation, selection, and inheritance of organism features.[21] This subsection describes each of these key elements of biological evolution as well as some examples of the diverse types of biological consequences and functional changes biological evolution has produced.

a. Variation

In biological systems, organism variations of evolutionary significance are generally achieved via changes in genetic features that dictate corresponding changes in organism characteristics.[22] Where a genetic change from a prior genetic makeup leads to an organism feature with some desirable consequence in organism survival, the changed version of an organism will tend to survive more frequently than the unchanged version and, over time, the altered version will tend to displace the unaltered organism.[23] The starting point for these processes is the generation (or at least the fresh presence) of new genetic variants. Relevant sources of new genetic variants include:

- **Mutations** – Random changes in DNA sequences that can introduce new organism features;[24]

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[21] *See* Geoffrey M. Hodgson & Thorbjørn Knudsen, *Why we need a generalized Darwinism, and why generalized Darwinism is not enough*, 61 J. OF ECON. BEHAVIOR & ORG. 1, 1-3 (2006); Deaniel C. Dennett, DARWIN'S DANGEROUS IDEA 343 (1995).
[22] D. J. Futuyma & M. Kirkpatrick, EVOLUTION 142 (2017).
[23] *See* E. Mayr, WHAT EVOLUTION IS 98 (2001).
[24] *See* M. Kimura, THE NEUTRAL THEORY OF MOLECULAR EVOLUTION 56 (1983).

- **Genetic recombination** – Reshuffling of genes during sexual reproduction can create genetically varied offspring;[25] and
- **Gene flow** – Migration of individuals between populations can introduce new genetic material and new genetic variations.[26]

b. Selection

In natural settings, variants of organisms with features that give the organisms advantages in survival and reproduction tend to be selected and promoted, while unaltered organisms lacking these features fare less well and eventually disappear.[27] Selection processes favoring variants with environmental advantages include:

- **Environmental selection** – Features that increase survival in a specific environment will tend to enhance the prevalence of organisms with the advantageous features in that environment (e.g., camouflage in prey animals);[28]
- **Sexual selection** – Features that improve reproductive success (e.g., bright plumage in peacocks to attract mates) will tend to increase the prevalence of variants of organisms with those features;[29] and
- **Artificial selection** – Features emphasized in human-driven artificial selection processes (e.g., selective breading to change plant varieties) can increase the prevalence of variants of organisms with targeted characteristics.[30]

c. Inheritance

Inheritance – or the continuation of organism features across time and multiple generations of organisms – is another key element of biological evolution.[31] This continuation is accomplished by the transmission of genetic information from parents to offspring and the replication in the offspring of beneficial features of the parents.[32] Genetically determined features of the parents that are preferred in survival thus become features of the offspring as well giving the offspring comparable survival advantages. This is in contrast to behavioral advantages – such as exercise patterns producing superior health in parents that are not genetically linked and therefore not passed on via genetic means to children – which may

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[25] *See* N. H. Barton & B. Charlesworth, *Why Sex and Recombination?,* 281 SCIENCE 1986, 1988 (1998).
[26] *See* M. Slatkin, *Gene Flow and the Geographic Structure of Natural Populations*, 236 SCIENCE 787, 788 (1987); University of California Museum of Paleontology, *Genetic Variation* (2020), https://evolution.berkeley.edu/evolution-101/mechanisms-the-processes-of-evolution/genetic-variation/.
[27] *See* J.A. Endler, NATURAL SELECTION IN THE WILD 123 (1986).
[28] *See* H.B.D. Kettlewell, *Selection Experiments on Industrial Melanism in the Lepidoptera*, 9 HEREDITY 323, 330 (1955).
[29] *See* M. Andersson, SEXUAL SELECTION 215 (1994)
[30] *See* C. Darwin, THE VARIATION OF ANIMALS AND PLANTS UNDER DOMESTICATION 287 (1868).
[31] *See* T. Dobzhansky, GENETICS AND THE ORIGIN OF SPECIES 67 (1937).
[32] *See* R.A. Fisher, THE GENETICAL THEORY OF NATURAL SELECTION 45 (1930).

provide a survival advantage to one generation but not continue beyond that point to provide any advantage to children.

A key implication of inheritance of features for evolutionary purposes is that desirable features with survival advantages are continued through multiple generations and form the basis for additional feature changes and survival testing. The consequences of continuation in this regard is that multiple small changes in functionality can accumulate to produce major changes in functionality over time.[33] Each incremental change that has a survival advantage will tend to prevail in selection processes and subsequent populations (and bases for further changes) will possess the early changes. Sequences of desirable changes (and their functional advantages) will add up. New changes will build on old ones. Greater levels of functionality will be achieved by small movements in organism features and associated small gains in functionality even though no guiding hand (other than the differential effects of adverse selection) determined the direction of improvement in the organisms involved.[34]

2. Diverse Outcomes: Examples of Natural Evolution at Work

Over many generations and extended time periods, populations of animals influenced by biological evolution can develop remarkable features that match their functional capabilities to desirable, survival enhancing interactions with their environments. Evolutionary change accounts for such diverse features of organisms as:

- **Structural adaptations** – Physical traits that enhance survival (e.g., the long neck of a giraffe used for reaching high vegetation);[35]
- **Behavioral adaptations** – Instinctive or learned behaviors that improve survival (e.g., bird migration patterns);[36] and
- **Physiological adaptations** – Internal processes that increase survival (e.g., antibiotic resistance in bacteria).[37]

While the products of natural evolution are literally all around us in the natural world, a few examples will illustrate the power of evolution in both producing variations among living organisms and matching the features of such organisms to the characteristics of surrounding environments. The following are three diverse examples of natural evolution at work.

<u>Darwin's Finches: Adaptive Variation</u>

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[33] S.J. Gould & N. Eldredge, *Punctuated Equilibria: The Tempo and Mode of Evolution Reconsidered*, 3 PALEOBIOLOGY 115, 120 (1977).

[34] R. Dawkins, THE BLIND WATCHMAKER: WHY THE EVIDENCE OF EVOLUTION REVEALS A UNIVERSE WITHOUT DESIGN 94 (1986).

[35] *See* R.E. Simmons & L. Scheepers, *Winning by a Neck: Sexual Selection in the Evolution of Giraffe*, 148 THE AMERICAN NATURALIST 771, 773 (1996).

[36] *See* T. Alerstam, BIRD MIGRATION 55 (1990).

[37] S.B. Levy & B. Marshall, *Antibacterial Resistance Worldwide: Causes, Challenges, and Responses*, 10 NATURE MEDICINE S122, S123 (2004).

One of the earliest analyses of evolutionary change was conducted by Charles Darwin based on his observations on the HMS Beagle from 1831-36. Darwin noticed that finches on different islands in the Galápagos Islands had distinct beak shapes, each suited to a specific type of food. He later hypothesized that these birds descended from a common ancestor and evolved different traits to exploit available resources.[38] Specifically, he concluded that it was probable that finches with long, narrow beaks were better suited for probing insects from tree bark, while those with short, thick beaks could efficiently crack seeds. Later studies have confirmed these sorts of evolutionary changes in the development of finches, including changes in beak size and shape within just a few generations based on differences in environmental conditions.[39]

Peppered Moths

Changes induced in peppered moths in response to industrial pollution highlight the ability of evolution to adapt organisms to the effects of man. In the early 19th century, a light-colored variant of the peppered moth was common, blending in with tree bark covered in pale lichens.[40] However, during the Industrial Revolution in England, coal pollution darkened the trees, making light-colored moths more visible to predators and resulting in reduced survival of the light variant. A dark-colored variant then became more common as it was able to better camouflage itself against soot-darkened trees. Evolutionary forces had shifted the preferred version of the moth to the darker version in response to pollution pressures.

However, the story of human-induced evolutionary changes in peppered moths does not end there. After pollution controls were implemented in the 20th century, soot levels went down, tree colors lightened, and the light-colored variant of the moth once again became more prevalent in the moth population.[41] Overall, these changes in moth characteristics reflect the speed with which short-term changes in environmental conditions – coupled with aggressive adverse selectors such as hungry birds – can produce rapid evolutionary changes in organisms.

Antibiotic Resistance in Bacteria

Darwinian evolution threatening public health drives the ongoing evolution of bacteria to gain resistance to antibiotic drugs.[42] When first introduced in the 20th Century, antibiotics were highly effective against broad ranges of bacterial infections. However, through a combination of mutations strengthening resistance and preferential survival of resistant strains of bacteria, many formerly effective antibiotics have far weaker impacts on some of today's infections.[43] The increasing prevalence of variants of bacteria resistant to older antibiotics has

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[38] *See Darwin's finches,* WIKIPEDIA, https://en.wikipedia.org/wiki/Darwin%27s_finches.
[39] *Id.*
[40] *See Peppered Moth Evolution,* WIKIPEDIA, https://en.wikipedia.org/wiki/Peppered_moth_evolution.
[41] *Id.*
[42] *See* University of California Museum of Paleontology, *Antibiotic resistance: delaying the inevitable*, https://evolution.berkeley.edu/the-relevance-of-evolution/medicine/antibiotic-resistance-delaying-the-inevitable/.
[43] *Id.*

prompted searches for new types of antibiotics with more sweeping effects across all types of bacteria. However, it seems likely that these new antibiotics, if found, will also be subject to waning effectiveness due to the evolution of bacteria strains that are resistant to the new antibiotics.

3. Directed Evolution: Gaming Natural Change

Directed evolution methods manipulate natural evolutionary processes to engineer new biological organisms and materials.[44] These methods treat evolution itself as a tool, subjecting it to human modification and improvement. Directed evolution processes mimic natural evolution but accelerate it by using iterative cycles of mutation and selection under controlled laboratory conditions. Directed evolution has been particularly successful in engineering biomolecules, particularly enzymes and proteins, to produce enhanced functionality.[45]

Directed evolution has revolutionized biotechnology, medicine, and industrial applications by generating optimized biomolecules for diverse purposes, including improved enzyme efficiency, novel catalytic functions, and therapeutic applications. The significance of directed evolution techniques was recognized in 2018 when Francis Arnold of the California Institute of Technology was awarded the Nobel Prize in Chemistry based on her pathbreaking work concerning the directed evolution of enzymes.[46]

Directed evolution techniques improve evolutionary results by expanding the range of biological variants subjected to evolutionary selection and by enhancing selection methods for advancing new variants with desirable functional features into further modification steps. Such improvements over natural evolution speed the identification of variants with superior functional characteristics in each evolutionary cycle. Over multiple cycles conduced within reasonably short periods, it is possible to accumulate improvements in functional characteristics and realize final, modified biological materials with markedly different functionality than the original sources. Remarkably, the fundamentally new functionality sometimes achieved through directed evolution is realized without any rational understanding at the outset of how to modify the materials involved to produce the resulting functionality.

As with simple evolution conducted through natural selection, directed evolution operates through variation creation and selection. However, directed evolution techniques use improved variation and selection methods to test broader ranges of candidates for superior functionality and reach selection findings quicker than natural processes. This combination of broader perspectives (realized though greater variation in selection candidates) and quicker

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[44] *See* F.H. Arnold, *Design by Directed Evolution*, 31 ACCOUNTS OF CHEMICAL RESEARCH 28, 28 (1998).
[45] *Id.*
[46] The Nobel Foundation, FRANCIS H. ARNOLD, NOBEL PRIZE IN CHEMISTRY 2018, https://www.nobelprize.org/prizes/chemistry/2018/arnold/facts/. The work leading to Professor Arnold's award promised to aid "environmentally friendly manufacturing of chemical substances, such as pharmaceuticals, and the production of renewable fuels." *Id.*

findings (realized through enhanced selection methods) permits more extensive explorations of modifications to biological materials that may produce desired functional improvements.

Viewed in abstract terms, directed evolution methods implement superior search strategies for seeking solution variations that produce desired functionality. Considering more potential solutions by generating and testing numerous variations should tend to increase the number of functionally superior solutions tested and the likelihood that a superior solution will emerge from testing. More rapid testing findings should allow more testing filters to be applied increasing the likelihood that only a solution with improved functionality will emerge. More specific testing will increase the value of teach testing step in ensuring that a solution identified as a "success" actually has the functionality that is desired.

Repeated applications of these sorts of steps in multiple cycles of directed evolution has the potential to systematically move searches for improved functionality though broad solution spaces and to identify as potentially valuable solutions without fully understanding the physical or engineering principles underlying why the solutions are working. Because these techniques can identify useful solutions without a full understanding of operating mechanisms or principles, directed evolution techniques can identify functionality solutions beyond the range of solutions capable of being generated by rational extension or modification of precursor designs using present knowledge. The latter are necessarily limited by the scope of present knowledge and out current abilities to extend it. Solutions based on directed evolution are just based on what works, as tested over and over again through directed evolution methods that move designs towards functionally successful designs without the need for knowledge of underlying science or technology.

The types of improvements in biological change now achieved through directed evolution have counterparts in the changes in technology designs spurred by patent incentives. Patents expand the variations considered in technology market testing and improve the features of that market testing. These impacts of patent incentives on technology evolution – implementing a form of directed technology evolution – are discussed at a later point in this article.[47] Because their counterparts in directed biological evolution may help us understand patent impacts, the remainder of this subsection provides a brief summary of the types of evolution variation and selection improvements that have accounted for the success of directed evolution methods.

a. Enhancing Variation of Candidates for Selection

Variations in genes undergoing evolutionary selection can be increased in a number of ways. One approach involves increasing the likelihood of random variations in the materials subjected to selection though the intentional injection of random copying errors – the

[47] *See* Section III, *infra*.

equivalent of mutations -- in producing sets of materials targeted for testing.[48] Another approach to increase gene variation involves combining fragments of genetic material through artificial means and then testing the functional attributes of the novel gene combinations varied in this way.[49] A third method involves focusing on one possible site of genetic alteration and attempting to replace genetic material at that site with all possible substitutes thereby creating all of the possible genetic variations that revolve around the genetic element of interest.[50]

Considered in abstract terms, these methods all expand the variety of candidates submitted for evolutionary testing and survival. Increasing random variations, creating new combinations of existing items, and assembling complete groups of alternatives to specific design elements all expand the range and diversity of new biological variants subjected to evolutionary testing. To draw a simple analogy, this is a bit like looking for gold across a broader range of ground than would be possible with prior techniques. All else being equal, a broader search should expand the likelihood of finding a desired item.

This principle has broad implications. For example, patent influences tending to expand the range of innovations subjected to market testing should have a similar desirable impact in increasing the likelihood of supplying technological items desired by parties in market settings. In this respect, patent rewards favoring the creation and market testing of broad ranges of outlier advances implement a form of directed evolution in technology change analogous to the increased range of organic variations created and tested in biological applications of directed evolution. The impacts of patents in broadening the range of technology designs considered in technology evolution will be discussed more thoroughly at a later point in this article. [51]

b. Accelerating and Focusing Testing of Evolution Candidates

A second type of directed evolution enhancement focuses on improving the ways that candidates for survival and further evolutionary advancement are tested and selected. Two subtypes of changes have been explored in directed evolution techniques: speeding the rate of testing and narrowing the specificity of testing results to better identify only tested variants with desirable functional features. Candidate screening enhancements such as these are critically important in directed evolution processes. As Nobel Laureate Francis Arnold succinctly puts it, with directed evolution "you get what you screen for."[52]

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[48] Mutation rates much higher than naturally occurring counterparts can be achieved via error-prone polymerase chain reaction (PCR) processing of genetic material, essentially an intentionally flawed gene copying process wherein multiple copies of source genes are made but are expected to have low fidelity to the source genes and to therefore reflect many mutations of their predecessors. *See* R.C. Cadwell & G.F. Joyce, *Randomization of Genes by PCR Mutagenesis*, 2 PCR METHODS AND APPLICATIONS 240, 240 (1992).

[49] *See* W.P. Stemmer, *Rapid Evolution of a Protein in vitro by DNA Shuffling*, 370 NATURE 1241, 1241 (1994).

[50] *See* M.T. Reetz, D. Kahakeaw & R. Lohmer, *Addressing the Protein Sequence Space through Directed Evolution*. 103 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES 989, 989 (2006).

[51] *See* Section III(B), *infra.*

[52] F.H. Arnold & G. Georgiou, *Preface* in DIRECTED ENZYME EVOLUTION: SCREENING AND SELECTION METHODS v (F.H. Arnold & G. Georgiou eds. 2003).

Put in information search terms, close links between screening criteria and design goals are needed to avoid wandering searches that either waste time on intermediary designs that only weakly advance the functionality desired in a design solution or take a search process entirely off track into dead end designs offing no increased functionality over predecessor designs. Screening methods that do not accurately screen for evolutionary candidates with increasing amounts of a targeted type of functionality are likely to produce cumulative screening results that maximize some other feature that was selected for but which is not the desired functionality. Later portions of this article will describe how patents tend to ensure that these errors do not plague testing of patented technology designs, but rather promote prompt testing of complete products incorporating patented advances for matches to consumer desires and needs.[53]

Accelerated Testing

Evolutionary revisions in biological settings have been speeded through the use of high throughput methods for screening biological variants. The common objective of these high-volume methods is to test multiple variants in parallel for superiority in some functional attribute. Hence, testing methods using fluorescence, colorimetric assays, or mass spectrometry have been able to produce simultaneous results describing the relative activity, specificity, or stability features of various variants.[54] With these results, the variants with the best functional features (in light of the features being targeted in overall evolutionary change processes) can be selected for mass scale copying and use in the next round of evolutionary change. Parallel processing of variant screening (or some other method for rapidly determining screening results) permits rounds of testing to be concluded promptly and multiple rounds of variation and testing to be advanced within short evolutionary redesign periods. Concluded quickly within time frames comparable to other types of engineering, evolutionary redesign has become a key tool for the construction of new biological materials.[55]

Adjustments in screening methods that speed testing improve evolutionary change processes by enabling more rounds of evolutionary change in a given period. More rounds of variation and testing imply an ability of evolutionary processes to explore a greater range of solution spaces with a correspondingly increased likelihood of moving closer towards maximizing a targeted type of functionality. If means for speeding selections are available, speed increases in selecting functionally superior variants offer means to improve evolutionary processes in diverse contexts.

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[53] *See* Section III(C), *infra.*

[54] See S. Govindarajan, V. Mann & F.H. Arnold, *Protein Stability by Directed Evolution*, 16 PROTEIN ENGINEERING 1627, 1628 (2003).

[55] Changes in biological materials enabled via directed evolution have transformed biotechnology, medicine, and industrial enzyme applications. *See, e.g.,* J.D. Bloom & F.H. Arnold, *In the Light of Directed Evolution: Pathways of Adaptive Protein Evolution*. 106 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES 99, 99 (2009).\

Focused Screening

Improvements in evolutionary changes have also been realized via enhancements in the specificity of screening methods to better identify only variants with clear superiority in promoting targeted functionality. Enhanced screening methods regarding biological materials are generally aimed at isolating clearly superior variants from large sets or "libraries" also containing other versions of a material and then ensuring that only the isolated versions are advanced through subsequent cycles of the directed evolution processes.[56] By ensuring that a narrower set of clearly superior variants are advanced across cycles within evolutionary processes, more selective screening methods can help to focus and improve subsequent rounds of evolutionary changes by starting subsequent rounds from uniformly high functionality points. Put simply, more selective measures ensure that subsequent rounds of evolutionary change build new results from the highest functionality plateaus achieved in prior rounds of change.

Adjustments that increase selectivity in evolutionary methods improve the quality of each round of evolutionary change, making the output of each round a better starting point for additional evolutionary variations and selections. Greater selectivity in selecting functionally superior variants – that is, reducing the prevalence of false findings of functional superiority among successful variants – is a means to improve the results of evolutionary processes across a variety of contexts.

Because they improve different aspects of selection processes, changes in selection techniques that target the speed and selectivity of selection can be used together to improve directed evolution methods. Whether this is possible in a given context will depend on the means available for producing rapid screening results and for selecting high functionality variants with few errors.

C. Innovation Development Through Technology Evolution

1. Essential Features of Technology Evolution

Technology evolution involves repeated steps generating and selecting useful artifacts in response to user needs and desires:

> The evolution of technology is driven by human needs and by needs created by other technologies. A technology is useful when it can satisfy a need better or more economically than previous technologies. Usefulness may change over time as new

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[56] A variety of techniques can be used to differentiate between desired and undesired variants and thereby select only variants with desirable features for additional evolutionary processing. For example, in one technique selection is achieved through cell survival, with only modified cells having beneficial characteristics surviving under selective conditions. This type of selection identifies desirable cell variants amidst a set of tested variants. Thus, particular variants that remain treatable via antibiotics can be identified by treating a range of variants with antibiotics following exposure to bacteria with antibiotic resistance generally threatening unmodified cells and seeing which, if any, of the variants survive. *See* S.F. Yuan, J. Jiang & H. Zhao, *Directed Evolution of Biosynthetic Pathways*, 7 METABOLIC ENGINEERING 212, 213 (2005).

inventions lead to more efficient technologies that quickly replace obsolete ones; for example, the transistor [] eliminated most uses of vacuum tubes. … Technologies that are successful and used repeatedly in different circumstances become encapsulated as modules or building blocks that in combination with other building blocks make possible the construction of further technologies.[57]

Component steps in technology evolution[58] involve generating new technology designs, testing new designs for superiority to past designs, retention (and often propagation) of relatively successful designs, and repetition of the design, testing and retention processes using the previously improved designs as a base.[59] The methods for accomplishing these steps vary across technical contexts, marketplace settings and user applications.[60] Evolutionary processes governing technology development account for "the immense variety of artifacts that are invented and put on the market, and for the superior quality of the few that eventually survive."[61]

Technology evolution through these sorts of practices not only influences resulting product designs, it changes surrounding technological knowledge and innovative practices. As recognized by Richard R. Nelson and Sidney G. Winter:

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[57] W. Brian Arthur & Wolfgang Polak, *The Evolution of Technology within a Simple Computer Model*, Santa Fe Institute Working Paper 2004-12-042 at 1 (Dec. 17, 2004), https://sfi-edu.s3.amazonaws.com/sfi-edu/production/uploads/sfi-com/dev/uploads/filer/25/61/25617f0e-394e-4a2c-9f60-0dedc2557d82/04-12-042.pdf. *See generally* John Ziman, *Evolutionary Models for Technological Change* in TECHNOLOGICAL INNOVATION AS AN EVOLUTIONARY PROCESS 3 (J. Ziman ed. 2000).

[58] Steps in the evolution of technology designs involve counterparts to the steps of natural variation and selection of organisms driving biological evolution. Some analysts describe the equivalent steps in technology change as involving "synthetic variation" and "synthetic selection" to emphasize that actions influencing technological change are human creations and subject to human modification. *See, e.g.,* William Bird, *A Question of* Evolution, 51 LES NOUVELLES 109, 109 (2016) ("We distinguish between Natural Selection (as in Nature) and Artificial Selection (as practiced by plant and animal breeders for centuries) and we introduce Synthetic Evolution and Synthetic Selection which is the development by human beings of innovations to produce new materials and physical, chemical and biological synthesis routes and processes in industry.").

[59] *See* W. Brian Arthur & Wolfgang Polak, *The Evolution of Technology within a Simple Computer Model*, Santa Fe Institute Working Paper 2004-12-042 at 1-2 (Dec. 17, 2004) (describing an evolutionary system for improving logic circuits involving steps of design generation, testing, and propagation of circuit designs), https://sfi-edu.s3.amazonaws.com/sfi-edu/production/uploads/sfi-com/dev/uploads/filer/25/61/25617f0e-394e-4a2c-9f60-0dedc2557d82/04-12-042.pdf.

[60] *See* W. Brian Arthur, THE NATURE OF TECHNOLOGY: WHAT IT IS AND HOW IT EVOLVES 107-30, 167-89 (2009) (finding evidence of technology evolution in the development of such diverse technologies as designs for aircraft, radar, spark radio, vacuum-tube radio, jet engines, the steam engine, railroads, computers, cyclotrons, mass spectrographs, polymerase chain reactions, and penicillin).

[61] John Ziman, *Evolutionary Models for Technological Change* in TECHNOLOGICAL INNOVATION AS AN EVOLUTIONARY PROCESS 3, 4 (J. Ziman ed. 2000). *See also* George Basalla, THE EVOLUTION OF TECHNOLOGY 2 (1988) ("The history of technology, a discipline that focuses on the invention, production, and users of material artifacts, benefits from the application of an evolutionary analogy as an explanatory device. A theory that explains the diversity of the organic realm can help us account for the variety of made things.").

> [S]tudies [of technological innovation] reveal that technology must be understood as involving both a body of artifacts, or practice, and a body of understanding. Some authors have concentrated on just one of these aspects. Thus, Petroski's (1992) exploration of *The Evolution of Useful Things* is concerned with artifacts, while Constant's (1980) focus in *The Origins of the Turbojet Revolution* is on the broad body of design understanding. But more generally, artifacts, practice and understanding co-evolve. Efforts to advance practice are informed by an often impressive body of understanding, often scientific understanding. Nevertheless, the process of inventing or designing is still to some extent "blind," because efforts to invent something new almost invariably reach well beyond what is known with certainty. Thus, despite the often strong knowledge base for advancing technology, the process remains evolutionary. Over time, practice and understanding tend to advance together.[62]

a. The Direction of Change – Form Follows Failure

Change in technology designs and resulting products[63] results from user demands motivating innovation via evolutionary processes. The starting point is typically product failure. The principle that form follows failure not function is a powerful directive force focusing most technology development. As described by its leading proponent Henry Petroski:

> the form of made things is always subject to changes in response to their real or perceived shortcomings, their failures to function properly. This principle governs all invention, innovation, and ingenuity; it is what drives all inventors, innovators, and engineers. And there follows a corollary: Since nothing is perfect, and, indeed, since even our ideas of perfection are not static, everything is subject to change over time. There can be no such thing as a "perfected" artifact; the future perfect can only be a tense, not a thing.[64]

The forms of new designs are dictated by what it takes to fix (or at least improve) previous designs. New designs frequently start with old designs and seek to change or eliminate the features that made the old designs "failures" – that is, not as functionally successful (or low cost) as potential users would like. Using many aspects of old designs can focus design attention and originality on changes to particular weak links in the old designs that have accounted for failure, thereby reincorporating many successful features in new designs without further design attention and reserving scarce designer attention to a few problematic

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[62] Richard R. Nelson & Sidney G. Winter, *Evolutionary Theorizing in Economics* 16 J. OF ECON. PERSPECTIVES 23, 39 (2002).

[63] Analyses of technology change in this article will refer to changes in products for convenience; parallel mechanisms for change apply to useful processes and other useful artifacts in society.

[64] W. Brian Arthur & Wolfgang Polak, *The Evolution of Technology within a Simple Computer Model*, Santa Fe Institute Working Paper 2004-12-042 at 22 (Dec. 17, 2004), https://sfi-edu.s3.amazonaws.com/sfi-edu/production/uploads/sfi-com/dev/uploads/filer/25/61/25617f0e-394e-4a2c-9f60-0dedc2557d82/04-12-042.pdf.

features of the old designs. In this focusing of new elements on past failures, the form of new designs follows from the nature of the failures of its predecessors.

b. Using Evolution When Rational Redesigns Are Not Enough

Effective technology design thus turns on how to span gaps in the functioning of past technologies and useful artifacts. Sometimes, rational thought is sufficient to create improved designs by reasoned analysis. Old designs can be reassessed and extended or modified based on existing technological and scientific knowledge to produce sufficient solutions to perceived functionality gaps or problems. In these sorts of rationally extended designs, well understood engineering or scientific knowledge is used to predict the implications and success of design changes in achieving altered functionality and to overcome the failed (or at least relatively undesirable) features of earlier designs.[65] If a path towards rational readjustment of old products to overcome the failures of prior products seems clear, one or more innovators in a competitive field will tend to perceive and take this path to produce improved products rapidly and gain associated commercial advantages over parties offering only older, flawed products with unmodified designs.

However, in some technology design settings past knowledge will provide very limited means to predict the success of design changes and to project the types of design changes that should be incorporated in new designs. There are several reasons why past knowledge supplemented by rational extension may not be enough to produce new designs. First, in every field, there are boundaries to existing technological knowledge – attempts to project the implications of design changes significantly beyond these limits will necessarily be poorly informed and often produce inaccurate projections of the functionality of altered design. The outer boundaries of existing technology knowledge in a field imply an associated limited range of potential design extension through reasoned analysis. Second, past knowledge in some fields is poorly extendable making it of little use in characterizing the functional implications of design changes. This is particularly true in fields like chemistry where small changes in the designs of chemical formulations are known to produce large but usually unpredictable shifts in the functional features of materials.

For reasons like these, past knowledge may sometimes be a weak tool for guiding technology change. Evolutionary design – that is the generation of new technology designs through evolutionary processes – can provide a substitute for rational extension or modification of old designs when the latter is ineffective. Technology change via evolutionary processes generates improvements without the need for prior understanding of the underlying features of new fields (or domains within existing fields) and the functionality of new artificial constructs within them. Evolutionary methods enable searches of potential technology design spaces with

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[65] In patent law, analysts have analogized this type of relatively common (and unpatentable) design revision to the work of a mechanic (such as an automobile mechanic) who applies widely known knowledge to get a device running and overcomes poor performance via fine tuning of device features known to influence device performance. *See, e.g., Hotchkiss v. Greenwood,* 52 U.S. 248 (1850).

relatively little initial information about which types of design solutions will produce successful results. In the face of underlying gaps in science and technology knowledge and corresponding gaps in innovators' abilities to project the functionality of design choices, technology evolution methods leading to testing of many possible design changes for possible functionality gains may be a valuable vehicle for change.

Beyond offering a means to proceed without substantial prior knowledge of the functional attributes of design choices, technology evolution methods has the additional design search strength of frequently involving multiple competing solutions generated and tested in parallel to resolve design uncertainties and achieve improved functionality. When a person is lost, he or she must generally try a single path in an initial attempt to find a way back home. With technology evolution, by contrast, a technologist who is lost in finding a new means to solve a problem with an old technology can simultaneously create and test numerous paths towards a successful result. This can speed the identification of design changes with at least some functional advantages over unmodified designs. By incorporating the functionally improved design changes in further rounds of design changes and parallel testing, a series of small functionality gains can be accumulated through multiple cycles and changes to produce a final redesign that is both much different than the original unmodified version and significantly better in the functionality targeted in the design process.

c. Features of Technology Evolution

Evolutionary processes advancing technology change involve steps with counterparts in Darwinian evolution governing biological organisms.[66] The essential evolutionary steps in technology evolution include actions varying technical designs that solve practical problems, testing the success of new designs in meeting user expectations and preferences, and continuing successful solutions as the basis for future evolutionary improvements.[67] Each of these steps is critical in producing technology changes that respond to (and increasingly match)

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[66] Similarities between technology evolution and biological evolution emerge because both are instances of change governed by broadly applicable (and largely unguided) systems searching for functionality amidst items providing the desired functionality. *See* S. Kauffman & W. Macready, *Technological evolution and adaptive organizations: ideas from biology may find applications in economics*. 1 COMPLEXITY 26, 26 (1995), https://doi.org/10.1002/cplx.6130010208; Peter Bentley, *An Introduction to Evolutionary Design by Computers* in EVOLUTIONARY DESIGN BY COMPUTERS 1, 5-8 (Peter Bentley ed. 1999).

[67] *See* Geoffrey M. Hodgson & Thorbjørn Knudsen, *Why we need a generalized Darwinism, and why generalized Darwinism is not enough*, 61 J. OF ECON. BEHAVIOR & ORG. 1, 1-5 (2006) (noting that broad ranges of complex systems incorporating variation, inheritance, and selection change via evolutionary processes). *Cf.* W. Brian Arthur, THE NATURE OF TECHNOLOGY: WHAT IT IS AND HOW IT EVOLVES 19 (2009) (arguing that unlike Darwinian evolution which proceeds through variation and selection, technology development proceeds via the combination of past technologies to produce new designs which are then tested). For the purposes of the discussions in this article, it is immaterial whether new technology designs are produced via variations on old designs or combinations of old designs; however they are achieved, products incorporating the new designs are then subjected to market testing resulting in evolutionary changes in prevailing technologies.

user needs and desires. The features of these essential steps in technology evolution are considered in greater depth in this subsection.

1) Variation of Technology Designs

To move from existing technology solutions serving practical needs to something better, designs for the better solutions must be generated and presented for possible widespread adoption.[68] Absent technology variation producing new designs, technology development will simply stagnate. Generally, new variants in technology artifacts are generated by inventors acting as technology designers.[69] New inventions are new variants that can be subjected to testing in evolutionary processes.

Unlike natural evolution where most new variants are randomly created via mutations of prior living forms, technology variants are humanly created and generally targeted at realizing useful ends. This targeting means that the range of technology variants will usually be more functionally focused than biological counterparts even though many technological variants may still fail to function well or may function less well than other existing technologies used for the same purpose, making the new technologies unwanted surplusages. Nonetheless, the targeting of technological variants towards specific functional ends should generally speed the pace of technological evolution in moving technological designs towards improved functionality since most of the candidate technologies entering evolutionary testing and selection have some degree of relevant functionality by design.

Completeness in technology designs matters. Variations of technology designs must be realized in forms complete and concrete enough to support market testing if they are to compete with prior, unmodified designs and gain adoption. In technology change (as in many

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[68] In evolutionary systems achieving change via Darwinian evolution – that is, via evolution steps having counterparts to the evolution patterns recognized by Darwin in nature – a system must possess a mechanism whereby variety occurs and is replenished among the items that are subject to change. Geoffrey M. Hodgson & Thorbjørn Knudsen, *Why we need a generalized Darwinism, and why generalized Darwinism is not enough*, 61 J. OF ECON. BEHAVIOR & ORG. 1, 5 (2006). In biological systems, these mechanisms for generating variations are provided by genetic recombination and rare mutations. *See id.*

[69] The emergence of most new technology variants via purposeful design rather than random variation provides a directionality to technology evolution:

> "[T]he inventor, by the manipulation of intangible mental models, is able to design – or "breed", or "artificially select" – far more promising variants than would turn up by chance. But the inclusion of design does not entirely bar an evolutionary approach. What it signifies … is that imaginative linkages with selective functions are established between different points along the historical trajectory of the system. The range of feasible variants at a given moment is not limited solely by *present* circumstances, such as the materials and tools currently available: it is also conditioned by memories of *past* circumstances, such as unsuccessful configurations and ideas, and by mental images of future circumstances, such as of a hypothetical device in action.

An End-Word in TECHNOLOGICAL INNOVATION AS AN EVOLUTIONARY PROCESS 312, 315 (J. Ziman ed. 2000).

evolutionary processes) "[w]hat really counts is the various actions actually tried, for it is from these that success is selected, not from some set of perfect actions."[70]

Diverse design approaches are also important. Broad diversity in technology variations will tend to increase the likelihood that a functionally superior design will be presented for testing. If the same engineering and science principles are guiding and constraining every new technology design, the range of available innovations will be narrower and inferior to a system where at least some innovators depart materially from conventional principles and generate new outlier designs that reflect non-obvious design elements that differ in some functionally important way from advances emerging from the bulk of contemporary innovations.[71]

Efforts to create technology variations entering public usage and impact may face countervailing forces tending to discourage such variations. Commercial realities may promote technology stagnation rather than new technology development. For example, depending on market and consumer conditions, a company that is a potential innovator may perceive higher profits in devoting resources to new and flashy advertising encouraging additional sales of an older soap formulation than in allocating the same resources to speculative and potentially unsuccessful efforts to develop an improved soap formulation. Faced with these sorts of cost-benefit realities, standing pat with an old technology will appear to be the preferable course.

In addition, consumer attitudes may discourage the development of new advances. Consumer attitudes may be biased against considering and adopting new technology designs, thereby lessening the commercial attraction of creating and marketing new technologies. All else being equal, a user of an older device will hesitate to move to a relatively unknown substitute with speculative benefits and potentially hidden costs. The perceived advantages of a new technology design must be compelling enough to overcome this hesitation. Hence, variations on old designs must not only possess increased utility in the eyes of users to have commercial value and attract business attention to innovations, the increased utility of revised designs may need to be quite large to overcome user hesitation in adopting the new designs.

2) Selection Via Testing in Marketplaces

Superior technology innovations will tend to propagate and displace substitutes if the innovations are embedded in products that enter markets, succeed in those markets, and are adopted by numerous users.[72] To accomplish this, new designs must typically attract the

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[70] Armen Alchian, *Uncertainty, Evolution and Economic Theory*, 58 J. OF POLITICAL ECON. 211, 220 (1950)

[71] *Cf.* Richard R. Nelson & Sidney G. Winter, Evolutionary Theorizing in Economics 16 J. of Econ. Perspectives 23, 27 (2002) (noting that under evolutionary selection "a system promoting a variety of experimental solutions to economic problems may perform better than one in which the same imperfect rationality guides every firm.").

[72] The selection step in evolutionary processes involves the greater survival in some environment of a entity with a modified feature over similar entities with the unmodified feature. The change in prevalence of the unmodified to modified versions of the entity may be gradual but eventually most of the entities will have the modified feature. *See* Geoffrey M. Hodgson & Thorbjørn Knudsen, *Why we need a generalized Darwinism, and why generalized Darwinism is not enough*, 61 J. OF ECON. BEHAVIOR & ORG. 1, 5 (2006). Thus, for example, in a cold environment, the

attention and resources of entities capable of both transforming raw designs into marketable products and manufacturing the related products. Commercializing entities must also – themselves or with the assistance of agents – undertake the often-considerable product distribution, advertising, and sales efforts needed to bring a new design to market testing. Furthermore, in highly regulated fields like the production and sales of pharmaceutical drugs and medical devices, regulatory testing steps may significantly add to market testing complexity and expenses.

The difficulties surrounding these various market testing tasks will impede testing of all but a few new technologies with relatively clear chances of overtaking existing technological solutions and gaining substantial market acceptance. Many new technologies may never get this far, being forgotten as mere ideas for unmarketed designs or briefly marketed products with limited sales and little public importance. Indeed, to the extent that likely product production or marketing problems are clear from the outset, these difficulties may have feedback effects on innovation. Innovators may tend to shy away from related lines of new technology development. No innovator will wish to invest large technology development resources in types of advances that are unlikely to be incorporated in marketed products and, therefore, unlikely to have any beneficial or profitable use by the public.

The point of market testing is to facilitate device users' choices between old and new devices in addressing particular practical needs and desires. New advances must win over users who have the option to stick with existing, familiar devices (either by just continuing to use their old devices or by buying additional new units of their familiar devices). Devices that succeed in this testing and gain market acceptance will tend to propagate and spread as far as corresponding user needs or desires extend. The resulting device sales will tend to match devices to consumer needs and desires until desires change or are better met by another round of innovations.

3) Propagation Into Further Rounds of Technology Change

Through accumulated sales, particularly successful new devices will tend to fill their respective market positions and form the basis for additional consumer expectations about desirable product enhancements. Successful features of these widely propagated products will tend to continue through multiple rounds of technology change focused on other features that are viewed as product weaknesses by users. Continuation of many features of devices through multiple change cycles ensures that the changes realized are cumulative and that later versions

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proportion of mammals with more fat or fir (providing insulation) is likely to increase through greater survival and replication. This differential survival and replication step in the face of the temperature stressor provides the selection step producing evolutionary change in this context. *Id.* In technology settings, the gradual displacement among users of unmodified devices with modified devices having superior functionality (including lower costs achieved without drops in functionality) will achieve a similar selection effect and promote technology evolution.

of the products involved reflect the sum of many design changes and associated gains in functionality.[73]

Even where actual device features do not continue, the functional features of old designs may shape consumer expectations and serve as a compelling design metaphor for later design efforts. Thus, the corded phone created expectations of how phones should work which carried over to inform user expectations about how successful cell phones should operate even though the latter operated with much different technical contents than their corded phone predecessors. The operational metaphor of a phone carried over and formed the base for extensive further innovation in cell phone design.

d. Factors Limiting Technology Evolution

1) Impediments to Variations

Some means to create design variants that improve technologies may be path dependent – that is, the use of certain types of materials or certain advances may be critical in the further development of a specific technology. Path-specific impediments to lines of research and the creation of technology design variants can impede technology evolution in these contexts. For example, constraints on materials needed for effective experimentation may preclude (or at least delay) certain types of improved designs from being generated. Patent constraints on certain types of production or commercial testing may limit some design efforts although mere intellectual testing to support the development of a new technology design would probably be sheltered from patent liability under the experimental use exception to patent infringement. However, the possibility that products based on a new variant of a previously patented base product would be limited in commercialization potential by the unwillingness of the patent holder controlling the base product to license the base patent at reasonable levels may discourage design variations along these lines, precluding the creation of related design variations as commercially uninteresting before they come into being.

2) Barriers to Testing

Safety concerns and related paths to regulatory approval – particularly for pharmaceutical drugs and medical devices – may sufficiently burden new design testing to leave

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[73] The essential continuation feature in an evolutionary change system is that there must be a means for useful information concerning solutions to particular problems to be retained and passed on into multiple rounds of solution improvement. *See* Geoffrey M. Hodgson & Thorbjørn Knudsen, *Why we need a generalized Darwinism, and why generalized Darwinism is not enough*, 61 J. OF ECON. BEHAVIOR & ORG. 1, 5 (2006). In biological systems, this continuation mechanism is sometimes referred to as "inheritance" and is achieved via information encoded and passed on from one generation to another via genetic sequences. *Id.* However, this is only one possible means of sufficient continuation of information on useful solutions. The key is that "[t]here must be some mechanism that ensures that some such solutions … endure and replicate; otherwise, the continuing retention of useful knowledge would not be possible." *Id.* In technology evolution, the continuation of successful technologies among public users (until trumped by better technologies) will ensure retention of the designs of the successful products and a tendency to use those products as starting points for further improvements.

promising new designs without testing results or with such results only many years after new design creation when potential investors in commercialization have lost interest. If regulatory concerns or other barriers to market testing – such as the costs of developing and presenting test products to meaningful numbers of potential customers – preclude effective selection of successful designs and separation of these from less useful counterparts among the available design variants competing for commercialization interest and opportunities, advancement of a new and potentially useful design variant may be stalled.

3) Difficulties in Introduction and Distribution

If the differences in products with new designs over prior products and the resulting net gains in to users are hard to describe, the introduction of new technology designs may be frustrated and no widespread use of the designs may be gained. These kinds of problems will tend to frustrate market testing and adoption of products with the new designs. Such problems may be particularly severe where technologies and their benefits and costs are particularly complex, necessitating expensive information processing to understand and properly weigh them. Issues of bias in favor of existing products and services will arise in many contexts as calls to shift to a new product or service require both new information processing on the part of a user and new risk taking on unknown aspects of a new product all of which can be avoided by just sticking with a previously adopted and familiar device.

e. Examples of the Diverse Results of Technology Evolution

Evolutionary processes have advanced changes in a wide range of technologies.[74] A few examples presented in this subsection will illustrate the potential impacts of evolutionary methods on the development of diverse technologies.

1) Aircraft Landing Gear Designs

In the first half of the 1930's, two competing approaches to aircraft landing gear designs competed for adoption in new aircraft designs. The resolution of this design competition provides a good example of technology evolution at work.[75]

Improvements in engine power were producing increased speed in new aircraft during this period. Reducing aircraft drag at the new elevated speeds was an important design concern. Landing gear designers took two fundamentally different approaches to minimizing aerodynamic drag from landing gear: 1) retractable gear that were shifted into the interior of an aircraft during flight creating a smooth fuselage with little drag or 2) fixed landing gear that

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[74] *See generally* George Basalla, THE EVOLUTION OF TECHNOLOGY (1988).

[75] For an account of technology evolution concerning aircraft landing gear designs, see Walter G. Vincenti, *Real-World Variation-Selection in the Evolution of Technological Form: Historical Examples* in TECHNOLOGICAL INNOVATION AS AN EVOLUTIONARY PROCESS 174, 182-87 (J. Ziman ed. 2000).

were not moved after takeoff but were enclosed within aerodynamically streamlined covers to lessen their drag during flight.

Both approaches went through numerous variations and improvements by designers seeking the attention and acceptance of aircraft buyers. Ultimately, retractable landing gear won out for most large commercial aircraft as the speeds these planes reached rose significantly and no improvements of fixed landing gear were able to produce the type of aerodynamic results possible from retractable gear at very high speeds. The changing operating conditions of the very fast aircraft created selection criteria that adversely selected against fixed landing gear designs. Fixed gear became effectively "extinct" among large, fast commercial aircraft although the simpler designs of fixed gear continued to prevail in many private aircraft that were flown at lower speeds.

2) Antenna Designs

In some engineering fields, the advantages of engineering design through evolutionary frameworks is well established. For example, evolutionary designs have had considerable success and acceptance in the development of antenna designs:

> Researchers have been investigating evolutionary antenna design and optimization since the early 1990s and the field has grown in recent years as computer speed has increased and electromagnetics simulators have improved. Many antenna types have been investigated, including wire antennas, antenna arrays, and quadrifilar helical antennas. In addition, the ability to evolve antennas *in-situ,* that is, taking into account the effects of surrounding structures, opens new design possibilities. Such an approach is very difficult for antenna designers due to the complexity of electromagnetic interactions, yet easy to integrate into evolutionary techniques.[76]

As this example illustrates, changes in technological designs developed through evolutionary methods can be effective means to overcome not only uncertainties regarding the functional implications of internal design changes but also further uncertainties about which design variants will work best in the particular operating contexts. To the extent that computers can aid in the progress of the evolution of technologies, this type of design approach also opens up the possibility of frequent technology changes to produce personal design solutions or business-specific technology revisions.

3) Software Designs

Evolutionary models for developing and testing software designs are central methods in certain programming settings. As noted by one observer:

[76] Jason D. Lohn, Gregory S. Hornby & Derek S. Linden, *An Evolved Antenna for Deployment on NASA's Space Technology 5 Mission* in GENETIC PROGRAMMING THEORY PRACTICE 2004 WORKSHOP ch. 1 (May 2004), https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=6544cf41d2fba96293fe5a47476faa7bb358e5b8.

> Engineering and computer science are undergoing a Darwinian revolution. [C]omputer scientists have hijacked the idea of "technological evolution", transforming it from a metaphorical model of historical change into literal methods for doing evolutionary engineering using explicit processes of random variation and selective replication inside computers. These methods, including genetic algorithms, genetic programming and evolution strategies, have attracted exponentially increasing interest as powerful ways of finding good engineering solutions to hard, complex, real-world problems.[77]

Computer-implemented evolution of software designs evolution may significantly strengthen software design processes in several ways over past processes that relied on human creation of software variants and human evaluations of software in market testing of variants to determine their fitness in meeting user needs. Human minds are not as good as computers in generating numerous variations in software code and in rapidly completing quantitative fitness evaluations of the numerous code variations in governing computer operations and producing desired outputs. Human overseen markets are not as fast or as free from biases as computers in generating software fitness accounts. There is therefore a zone – where numerous variations are at stake and the realization of even modest functional gains from variants is of potential importance – where computer-mediated software evolution may produce better results than prior human-based programming methods.[78]

III. Impacts of Patents on Technology Evolution

A. Patents as Agents of Directed Evolution Favoring Outlier Technologies

Patents are fuel for the engine of technology variation, emphasizing the creation and disclosure of greater numbers of outlier advances meeting patent standards for non-obvious inventions. The incentives created by patent rights implement a form of directed evolution distinctively advantaging the development and adoption of outlier technologies departing materially from existing technical knowledge.[79] Like directed evolution aimed at biological

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[77] Geoffrey Miller, *Technological Evolution as Self-Fulfilling Prophecy* in TECHNOLOGICAL INNOVATION AS AN EVOLUTIONARY PROCESS 203, 203 (J. Ziman ed. 2000).

[78] *See id.* at 214-15.

[79] Evolutionary principles have been used to analyze patent rights but only in very narrow analyses. For example, Erik S. Maurer has argued that forces of competition and evolution among technology innovators restrict the consequences of certain patent law interpretations. Eirk S. Maurer, *An Economic Justification for a Broad Interpretation of Patentable Subject Matter,* 95 NW. U. L. REV. 1057 (2001). He contends that aspects of technology evolution – specifically market driven selection or rejection of patented advances over prior technology designs – limit the impacts of broadly inclusive interpretations of patentable subject matter and the attachment of patent rights to wide ranges of new advances. *See id.* at 1088-91. Maurer points out that only patent rights attached to highly popular advances will have meaningful consequences, with rights attached to advances having no market acceptance being the practical equivalent of no rights at all. He contends that this justifies extending patent rights to a broad range of subject matters to ensure that the widest set of advances are subjected to market tests. *See id.* at 1987-91.

Maurer's analysis interestingly considers the impacts of technology evolution on the proper scope of patent rights rather than the impacts of patent rights on technology evolution – the focus of the present article. It changes, patent rights ensure that more design variants are created and tested in evolutionary processes governing technology change. In this way, patents effectively create an artificial selection pressure favoring the inclusion and success of patentable outlier innovations in technology evolution. By bringing more outlier designs within technology evolution processes, patents expand the technology design space searched by evolutionary processes and increase the diversity of technology design solutions brought to public access and benefit.[80]

Patent influences ensure that 1) a broader range of advances that are outliers in their fields are developed than would otherwise be the case, 2) that greater attention is given to the commercialization and market testing of outlier advances against public demand, and 3) that innovators (both individual and organizational) capable of producing popular advances based on outlier technologies are rewarded and strengthened in further work on additional outlier innovations. Each of these three effects will tend to bring more outlier advances to public availability; taken together, they reflect major influences of patents on the breadth of technology change and the delivery to users of new technologies breaking from prior knowledge.

B. Encouraging Outlier Technology Development

Patents encourage the creation of technology designs that are outliers in their fields. For purposes of the discussion here, an outlier advance is the same as a non-obvious advance under patent law – that is, an advance which would not be obvious to a well-informed practitioner of average skills in the same field of technology as the innovator who produced the advance.[81]

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rightfully brings product selection mediated by market forces to the forefront of technology development but fails to emphasize that patents influence product selections by biasing market driven selection processes towards increased consideration and selection of outlier innovations differing materially from prior advances in their fields. The focus in this article is on how patents improve product selections rather than how product selections improve patents (if at all) as considered by Maurer.

[80] The lure of patent rights can also increase the speed of search of new innovation spaces as competing innovators emphasize speed in research to be the first to invent a patentable technology and to thereby be the first to file for a patent and be the sole party to gain a patent rights over the technology.

[81] *See* 35 U.S.C. § 103; *KSR v. Teleflex*, 550 U.S. 398, 415 (2007); *Graham v. John Deere Co. of Kansas City*, 383 U.S. 1, 17-18 (1966).

Under prevailing views of obviousness in innovation, the following sorts of extensions of past technologies will typically be obvious advances not qualifying for patents and, consequently, not subject to the special boost to outlier advances provided by patents as described in this article:

> Combining prior art elements according to known methods to yield predictable results;
> Simple substitution of one known element for another to obtain predictable results;
> Use of known technique to improve similar devices, methods, or products in the same way;
> Obvious to try solutions to design problems involving choosing from a finite number of identified, predictable solutions, with a reasonable expectation of success; and
> Known work in one field of endeavor that prompts variations of it for use in either the same field or a different one based on design incentives or other market forces if the variations are predictable to one of ordinary skill in the art.

1. The Substantive Knowledge Needed to Generate Outlier Advances

Outlier advances may be beyond the obvious foresight of average practitioners for a number of reasons. One is that average practitioners lack the substantive knowledge needed to project and predict the likely success of particular technology design changes, rendering these design changes non-obvious when produced by the few parties who do have the requisite knowledge.

The creation of some outlier advances may exceed the knowledge and skills of most practitioners because the designs reflect new scientific or engineering findings leading to new technology design paradigms that are as yet unknown to most practitioners. Technological design paradigms encompass a range of features affecting technology use and development, including "the body of technological artifacts and processes, the way they are used, the body of understanding about a technology, and an assessment of the prevailing technical options."[82] Changes in technologies generally proceed within stable paradigms and then shift to new paradigms as the means to construct artifacts in fundamentally new ways in accordance with the new paradigms are discovered. In these processes, technological paradigms serve as counterparts to scientific paradigms framing periods of scientific experimentation and knowledge.[83] With the formulation and application of new paradigms, both scientific and technological developments and understanding can move in fundamentally new directions.[84]

By encouraging attention to outlier advances involving new design paradigms, patents tend to promote punctuated evolution of technologies.[85] Technologies subject to punctuated

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See KSR, 550 U.S. at 417-18.

Conversely, non-obvious advances for which patents are available (assuming other patent law requirements are met) include innovations that well-informed persons having ordinary skill in the relevant technical art would not have pursued as a likely means to solve a particular practical problem. To determine if a given advance is such a non-obvious outlier, the content of an advance must be carefully compared to technology information already available in the relevant field of technology:

> "[To determine under the Patent Act if an advance was obvious when made and therefore unpatentable], the scope and content of the prior art are to be determined; differences between the prior art and the claims [describing the advance] are to be ascertained; and the level of ordinary skill in the pertinent art resolved. Against this background, the obviousness or nonobviousness of the subject matter is determined."

See Graham, 383 U.S. at 17-18. The

[82] Su Jung Jee, Minji Kwon, Jung Moon Ha & So Young Sohn, *Exploring the forward citation patterns of patents based on the evolution of technology fields*, 13 J. OF INFORMETRICS 1, 3 (2019).

[83] *See* T. S. Kuhn, THE STRUCTURE OF SCIENTIFIC REVOLUTIONS (1963).

[84] *See* Jung Jee, Minji Kwon, Jung Moon Ha & So Young Sohn, *Exploring the forward citation patterns of patents based on the evolution of technology fields*, 13 J. OF INFORMETRICS 1, 3 (2019).

[85] As an example of a patented advance spurring several types of punctuated technology evolution, consider the development of the polymerase chain reaction (PCR) method for genetic material copying. This patented method not only revolutionized processes for gene copying (resulting in the Nobel prize for its originator Kary Mullis) but also created dramatic changes in fields that depended on easily accomplished gene copying. Both the gene copying field and the dependent fields influenced by gene copying were transformed by punctuated evolution, with

evolution undergo periods of modest change through extension or optimization within stable paradigms but lurch forward in new directions when reconsidered and redesigned in accordance with new design paradigms. Back and forth movement of technologies via intra-paradigm modifications and extra-paradigm leaps to new technology plateaus define overall technology change.

Patents tend to encourage more paradigm shifts in technology designs and promote more market testing and public acceptance of new products built upon new paradigms. By departing from convention wisdom, non-obvious designs potentially qualifying for patents also present the type of fundamentally new design approaches underlying paradigm shifts in engineering and science thinking. Whether they will serve as a new paradigm for later technology development depends on whether the non-obvious designs achieve widespread acceptance through market testing. By encouraging talented innovators to work on, recognize, and disclose fundamentally new technology design approaches, patent interests can enhance both the range of technologies underlying practical products and the number of fundamentally new design shifts influencing future technological and scientific analysis.

Of course, non-obvious design changes are not coextensive with technology paradigm shifts. Some non-obvious new designs may just extend old designs within existing design paradigms but in previously untried and somewhat unpredictable ways. These sorts of new designs will still be outliers qualifying for patent protections (because their functional features would not be predictable to average practitioners in their fields) yet would not involve the application and disclosure of new design paradigms. A full analysis of the fraction of patentable design outliers that reflect design paradigm shifts is beyond the scope of this article. For present purposes, it is only claimed that patents bias innovation production and disclosures towards outlier advances departing materially from past conventions (whether the departures involve new design paradigms or not). This bias results in the creation and disclosure of more outlier technologies than would be generated absent the special incentives of patent interests.

2. Attracting the Efforts of Specially Capable Parties

Patent influences can encourage parties with exceptional knowledge and technology development skills to apply their rare abilities to the creation and disclosure of outlier technology designs through a number of mechanisms as summarized in the remainder of this subsection.

a. Gaining the Attention of the Best Researchers

1) Promoting Entrepreneurial Leadership

substantial and fundamental changes in technology functionality triggered by the introduction of the PCR process. *See* U.S. Patent 4,683,202 (July 28, 1987); Royal Swedish Academy of Science, *Press Release* (Oct. 13, 1993) (noting that "[t]he biomedical applications of the PCR method are … legion."), https://www.nobelprize.org/prizes/chemistry/1993/press-release/.

If outlier advances tend to emerge from a few highly talented researchers, then one potential impact of patent interests is to draw the attention of such scarce researchers towards the types of engineering projects that are likely to produce outlier advances. Patents can accomplish this by heightening the potential value of startup enterprises in which the value of a significant engineering advance can be commercialized via company sales turning largely on transfers of associated intellectual property as protected by patents. Put simply, patents are at the center of the promise of many startup business models and their potential for large rewards upon sales of the startups to larger corporations that will complete full commercialization of technological breakthroughs identified by the startups. However, absent patents, there is often little transferable content to sell and, hence, little commercial lure to attract talented scientists and engineers into technical leadership roles in highly risky startup enterprises.

2) Attracting Leading Researchers To Create Practical Supplements to More Theoretical Work

The best minds in certain fields of science and engineering may see their primary careers and accomplishments in academic research. Faculty members focused on unapplied research results may find work on practical implementations of their findings a time consuming and negative distraction from their most important work. The commercial attraction of patent-mediated rewards for involvement in technology development efforts can provide the motivation to focus on practical offshoots of unapplied state of the art research results. Whether patent-enhanced rewards flow to faculty members via terms of university patent assignment agreements that typically give faculty inventors a significant fraction of patent royalties realized by their universities or via actual involvement of faculty members in startup companies aimed at developing and commercializing offshoots of the faculty member's research, the patent-enhanced commercial potential that attaches to outlier advances provides a strong reason for faculty members to go beyond mere unapplied research findings to consider how their work can produce related commercial products of significance to the public.

3) Encouraging Follow Through on Practical Advances

Where branches of new technology start with the discoveries of academic researchers (perhaps working with entirely new approaches to scientific research that generate equally untried approaches to practical problems), follow through by the researchers in providing detailed know how and technical details to parties perfecting products or services built upon the researchers' work may be needed to produce useful and commercially valuable products and services. Patent-mediated rewards (or at least the potential for such rewards) provide a lure to gain the attention of researchers to these otherwise thankless follow-through tasks.

b. Altering Research Patterns to Favor Outliers

1) Encouraging Searches for Outliers

Patents can help shift technology design programs towards searches for outlier designs. Often these programs will be driven and targeted by consumer demand for a widely used product. A product (or service) that has gained substantial popularity among users signals a significant user need being met by the product. Efforts to develop new technologies to serve the same need will be encouraged by the consumer demand indicated by the success of the existing product. However, two forces may discourage research to develop new technologies supporting products that will displace an existing popular product serving the same need.

First, any substitute product based on a new and unfamiliar technology must overcome product users' wariness about the risks of shifting to an unfamiliar technology and abandoning a known solution embedded in a presently dominant product. A new technology may or may not provide superior functionality to particular users – only use of the technology in a user's circumstances will provide concrete evidence of superior functionality for the user. The untried technology may also have unforeseen side effects that diminish the net attractions of the new technology. All these sources of uncertainty weigh against adopting the new technology as a substitute for a tried-and-true solution as represented by the older technology embedded in the presently dominated product with which consumers are highly familiar. While these barriers to adoption of a new technology can be overcome, it may take a large amount of projected gain from adoption of the new technology to convince skeptical users to embrace a change. Recognizing that a significant increase in functionality is needed to have a meaningful impact on user preferences and commercial markets, parties capable of producing revised technologies may forego the necessary research efforts because they are deterred by the amount of incremental functionality they must produce to succeed.

Second, producers of presently successful products may limit their efforts to change or enhance their products through new technologies because non-research expenditures are a better means to generate profits. Once a product has been perfected in design adjustments, manufactured in quantities, and gained some marketing success, additional amounts spent on enhanced advertising or in making non-functional product changes (e.g. adopting more colorful product packaging) may be better ways to produce more profits per dollar spent than entering into a research program with unknown total costs and unknown likelihoods of success. At least for parties with the strongest relationships to likely product users – i.e., those vendors presently selling the users a dominant product – non-research spending lies in tension with research outlays and may win out as a preferred means for seeking additional profits. Where this the case, research into new technologies that might improve the functionality of the dominant product will be neglected in favor of other means of enhancing profits.

Even where parties seek new technologies to enable substitutes for a presently dominant product, their technology development efforts may emphasize ordinary redesign steps rather than searches for outlier advances departing from prior knowledge in their fields. Rational extension of past designs producing new designs with a high probability of success will be the low risk means to pursue redesigns with payoffs for time spent. By contrast, efforts to seek outlier designs based on entirely new design approaches may have a much higher chance of project failure. The latter may discover no useful design approaches, or discovered approaches may have more adverse side effects than practical gains, or discovered approaches may have net positive functionality (taking into account side effects) but the positive functionality achieved may be no better than the results realized by the present, well known technology underlying a dominant product. All of these results of trying to "swing for the fences" to produce non-obvious outlier advances are instances of design failure because they enable no new products of greater value to users and, hence, no products of commercial value. Rather than risk sinking enormous resources into quests for outlier jumps away from earlier design approaches, the safe course for researchers in many contexts will be to adjust older designs and produce improved but obvious extensions of earlier technologies. These technologies may have superior functionality to their predecessors – and have a chance of enabling commercially important new products accordingly – but they will not meaningfully expand the range of outlier design approaches and paradigms available to subsequent technology innovators.

Patent rights and incentives offer means of both encouraging more active research into new technologies and pushing such research towards more searches for fundamentally new technology designs that are non-obvious additions to prior technology knowledge. By attaching special commercial rewards to the risky searches for outlier advances at the fringes of present technology designs, patents will tend to focus additional attention and activity toward exploring those fringes and, over time, should produce more advances that are outliers materially expanding the knowledge tools available in their respective technology fields.

2) Supporting the Creation of Startups That Develop New Outliers

Patents can also enhance research concerning outlier designs for new technologies by shifting the modes in which key research is conducted. Patents aid in the creation and financing of specialized research and product development entities – usually in the form of startup companies – in which a few parties with technological vision beyond that of most specialists in their field can experiment with new technology designs and perfect related parties. The goal of these specialized entities is typically to bridge the gap between raw, unapplied technology ideas and designs for products or services that respond to user desires and that are defined (and even test marketed) to a degree that larger entities (usually large corporations) can take the new designs, produce related products or services at scale, deliver these to users in high volume, and distribute to results of outlier technology designs to widespread user groups.

The key to much of this process is the protection of the underlying new technology ideas via patent rights. Patents held by startup company founders aid these parties in gaining investments and other financing that supports their efforts to perfect the technologies and transform them into products or services desired by users. This funding may also support efforts to provide the products or services on a small scale to confirm the marketability of these products and services. Once their designs are perfected and their marketing potential is established, the products and services are transferred to bigger entities, typically via company buyouts in which the startups involved are purchased along with all their assets by a bigger company. These buyouts often hinge on patent interests as the large entities are in effect paying for the exclusive opportunity to commercialize the new technologies involved as protected by the patent rights that are transferred to the large entities as part of the transfer of assets from the smaller startups. Hence, both during the life of startups and at the critical buyout exit stage, patents play key roles in enabling startup companies to develop patentable outlier technologies and to bring related products and services to greater public availability.

2. Drawing Attention to Unexpectedly Encountered Outliers

Patents can also ensure that outlier advances, when realized accidentally even though not targeted in research, are not lost to public knowledge but instead are utilized in product development and disclosed to enter the array of technological tools available to subsequent innovators.

a. Offshoots of Commonplace Research

Outlier findings may be the unexpected offshoots of research conducted through commonplace research analyses. For example, efforts to extend past technology designs may produce levels or types of functionality that were unexpected. Designs incorporating these unexpected results would not have been obvious to parties of ordinary skill in the relevant field and will, if other patent requirements are met, qualify for patent protections and rewards. The potential for these rewards will make innovators attentive to these unexpected results and increase the likelihood that innovators observing such results will seek patents for them and make corresponding disclosures of their unexpected findings to the benefit of other innovators and the public.

In some fields – such as chemistry – the frequency of unexpected results of commonplace research may be high. In these fields, small changes in designs (for example, small changes in chemical compositions) can produce large and unpredictable variations in the functional features of the altered item relative to its unaltered form. Patents related to the nature of unexpected (and unpredictable) changes in functionality seen in experimental variations of items will ensure that the new functional attributes are disclosed and explored for the creation of new products (because the resulting products will have commercialization attractions benefitted by patent rights).

b. Recognition of Outliers Produced by Accident

Sometimes outlier designs are completed by accident and then recognized by parties as sources of useful functionality. For example, in *Townsend v. Smith*,[86] the court assessed a

[86] 36 F.2d 292 (C.C.P.A. 1929).

patented invention that was first accidentally reduced to practice (a screw threading machine was accidentally assembled with an improperly made part) and then conceived as a new invention when perceived by an observer as a new design for a device which performed a useful task.[87] These sorts of accidental inventions -- not at all the subject of conscious design but rather chance – can produce new technology information of substantial use to later device makers and innovators. Attaching patent rights to these accidentally achieved and unpredictable innovations helps to ensure that they are not lost to technical fields. Rather, with the incentives of patent interest, these advances are likely to be explored for their user applications and, where applications seem likely to serve many users, advance to public access through commercialization of products and widespread product sales.

C. Enhanced Market Testing of Outliers

1. Advancing Outlier Designs to Market Testing Regardless of Source

The attractions and enhanced commercial potential of patent rewards cause associated technology designs to be singled out more frequently for product development and market testing than other designs lacking patent protections. All else being equal, patent-mediated rewards and market exclusivity will add an increment of perceived value to patent protected technologies that is lacking in unprotected technologies. This increment of perceived value will, in turn, make it more likely that innovators and those who back them with investments will follow through on product development and market testing of the patent-protected technologies. This will be true regardless of how the patent-protected designs first emerged – that is, regardless of whether they were the targets of research, incidental findings, or accidental discoveries.

Patent protection enhances the status of outlier technologies in commercialization evaluations. The issuance of a patent regarding a given advance signals to potential investors that, in the estimation of USPTO examiners, the patented technology is a distinctive, non-obvious departure from the knowledge generally held in the relevant field. An uncommon advance of this sort, cloaked with the special protections against free rider exploitation provided by patent rights, will seem worthy of special attention by potential investors or acquisition specialists looking for technologies with unusual profit potential. As such, the attachment of a patent tends to lift its invention out of the commonplace range of everyday innovations and provide a starting point for more intensive types of market evaluation and testing not available to unpatented and unprotected advances.

2. Changing the Features of Market Testing

a. Focusing Attention on Entire User Demand

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[87] In its accidentally altered form, the device shifted from cutting single threaded screws to cutting double threaded screws. *See id.* at 294.

Marketplace exclusivity guaranteed by patent rights concerning an outlier technology will encourage investors and companies considering the development of products based on the technology to value the technology in terms of the full market demand likely to be met by the resulting products. Technologies solving widespread problems of significant value to potential technology users will warrant substantial attention by parties capable of bringing products to market; technologies lacking apparent value as seen in these terms will not merit attention and will be appropriately dropped from contention for scarce product development resources. In short, patent interests tend to tie market testing decisions for outlier technologies to the scope of projected user needs and value to be realized in technology use. Absent patent protections, potential commercializing parties could not be assured of capturing the full scope of market gains from a new technology since free riders might capture some or all of the market gains from the technology. Deterred by the fear of free riders, potential commercializers may tend to commit their time and investment resources to projects with greater perceived value rather than committing to risky schemes to perfect and commercialize largely unknown outlier technologies.

2. Willingness to Bear Potentially Large Product Development Costs

Even when a new outlier technology is identified as a possible basis for new products, unknowns surrounding product development may deter parties capable of commercializing the technology from undertaking the necessary efforts. Outlier technologies typically depart from previously prevailing knowledge about technology in their field; hence, extensive fact finding and experimental work may be needed to fully understand the outlier technologies, transform them into products, analyze the strengths and weaknesses of tentative product designs, and make product design revisions (sometimes many times) to realize the best possible balance of net positive product features. These costs of these preliminary steps – which do not even yet include the difficult steps of manufacturing, distributing, retail sales, and maintenance of products based on the loosely understood new outlier technologies – can be enormous.

Patents encourage product developers to take these risky steps as means to access the potential rewards of returns from full market testing. Without patents, parties capable of investing in product development would hesitate to do so on the grounds that their expensive efforts might fail outright (in which case amounts expended would be wasted) or their successful products might be brought to market, duplicated by competitors with little background research expense, and then much of the rewards from sales of products based on the new technologies would go to the competitors (in which case not only would the original product developer waste its development expenditures, it would also inadvertently strengthen its competitors). With patent protections, the market payoffs from product development should (for the term of the applicable patents) flow back to the product developer.

This still makes the development of products based on outlier technologies a risky endeavor (since many of these fresh technologies will not be capable of being transformed into successful products), but the greater promise of full market rewards under patent protections relative to highly uncertain rewards without those protections are likely to make a much broader range of outlier technology product development appear cost effective under patent protection than in the absence of such protection. Put simply, patent rights and the ability to project potential rewards across markets increase the value of risk taking in outlier technology development and will tend to ensure more such technologies are transformed into products that are ready for market testing and potential public adoption.

3. Willingness to Invest in Product Introduction

Like product development, the introduction of outlier technologies in user marketplaces involves some unusual risks and corresponding costs to parties promoting the adoption of the technologies. Because they are materially different from past technology designs (by definition), outlier technologies will be somewhat unfamiliar to potential users. These users may be concerned about a number of unknown features related to the new technologies, including how much it will cost (in both purchase prices and temporary lost productivity) to shift from their presently used technology to a product based on the new technology, what the benefits of using the new technology will be in the context of the users' particular activities, and what the costs or other detrimental features of using the new technology will be in the same environment. Parties seeking to have users adopt a fundamentally new technology must help inform potential users about topics such as these and overcome the associated hesitancy of users to make the jump from a familiar product solution based on an old technology to the relatively unknown world of a new product based on an unfamiliar and untried new technology.

Patent protections and the associated assurance that a party introducing a new technology will gain the associated market rewards (for the term of the related patents) will encourage the introduction of new outlier technologies with the type of marketing information and technology demonstrations needed to overcome user hesitancy. Marketing failure in these contexts is another type of risk that a new technology introducer will be hesitant to take on absent the reassurances of market exclusivity provided by patent protections. No party capable of introducing an new technology (perhaps to the party's existing customers who use a prior technology for similar purposes) will be willing to do so if product introduction efforts will educate their users to the advantages of the new technology only to have the users buy products based on the new technology from a competitor. This sort of free riding by competitors will only strengthen the competition. However, patent rights prevent this sort of undercutting of product introducers by ensuring that, if users are successfully informed about the advantages of a new outlier technology and make the shift to that new technology, the holder of the patent on the technology will be able to reap the resulting market gains from the shift.

As with product development expenditures, product introduction expenditures and risk taking are encouraged by patent rights. The promise of patent-mediated market rewards flowing to parties introducing new outlier technologies that solve user problems and achieve extensive market success encourages parties to make bets on the introduction of products based on patented outlier technologies and to give those bets the greatest chance for success by investing the product introduction resources that will help potential users understand the new products and make informed decisions about whether the new technologies are superior to their predecessors for purposes of the users' activities.

D. Differential Strengthening of Technologists Producing Successful Outliers

Patent rights can enhance technology evolution by differentially strengthening parties who have been successful in generating and marketing outlier advances. This impact of patent rights involves a somewhat different type of evolutionary effect than has been discussed to this point. The patent impacts previously discussed have involved patent influences on outlier innovations. However, patents can also have a somewhat different effect on innovators which carries over to expand the production of outlier technologies. Innovators as well as innovations are subject to competition and evolutionary change. Analysts have recognized that innovators generating patentable inventions are subject to "natural selection" based on the success or failure of their inventions in market testing.[88] By rewarding innovators who succeed in producing outlier advances with large public impacts, patent rights can strengthen highly capable innovators and increase the chances that they will produce additional outlier technologies with public benefits.

1. Ensuring Rewards Flow to Originators of Outlier Technologies

Patent rights help ensure that economic rewards for technologies that satisfy user needs are passed back to the innovators (both individuals and organizations) who produced the technologies. The mechanisms for rewarding, and thereby strengthening, originators of successful outlier technologies vary somewhat based on the sources of the technologies.

In academic settings, both university organizations and their individual researchers can gain significantly from the discovery of a commercially successful outlier technology protected by patent rights. Patent licensing gains received by some universities now amount to hundreds of millions of dollars. Individuals who make key discoveries will generally share in these gains. University patent licensing arrangements typically provide that university researchers (i.e. faculty, graduate students, and research staff) who have discovered inventions and applied for patents that are later successfully licensed by their universities will typically receive a percentage of the resulting licensing royalties. If an academic researcher wishes to seek even greater rewards from a discovery, he or she can join a startup company aimed at developing a university-originated technology in which case the rewards to the university researcher will be those provided to key startup employees. These rewards can include significant gains in company buyouts or, more rarely, favorable positions in initial public offerings (IPOs) of company stock.

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[88] *See* Eirk S. Maurer, *An Economic Justification for a Broad Interpretation of Patentable Subject Matter,* 95 NW. U. L. REV. 1057, 1091 (2001).

Research within startup companies can generate new outlier technologies as well. Where these technologies serve widespread user needs (or appear likely to and have perceived commercial value accordingly), company owners and key innovators can both reap significant rewards. Company owners who have backed startup company efforts to discover or develop a new technology can gain through related company buyouts and IPOs. The value given a company in a buyout or IPO will depend greatly on the value implied by the market exclusivity provided by the company's patents. Where company patents suggest control over a technology with the potential for extensive public sales and large commercial returns, the gains flowing back to company owners and key employees (such as important company innovators) will typically be correspondingly large. As essential sources of technologies (and related know how) that lie at the core of most of the value of high technology companies, originators of patented outlier technologies emerging from startup companies will typically gain substantial fractions of the overall value of a startup company realized through a company buyout or IPO.

Corporations that originate patented outlier technologies through their own research efforts will also typically gain substantial patent-mediated rewards where the technologies satisfy widespread user needs. A company holding patents on a widely used new technology can produce profits by licensing the patents to other parties that manufacture and sell products satisfying user needs or by making and selling the products itself. A company may also choose a hybrid strategy, making and selling patented products for some markets itself and licensing others to do the same for other markets. The choice of how to best satisfy market demand for a patented technology will vary from technology to technology. The overall point is that by holding the relevant patents, a company that originates an important new outlier technology will (for the life of the patents) reap the primary market benefits and commercial rewards from that technology.

Finally, regardless of the setting where an innovation was made, an innovator holding a patent (whether an individual or an organization) can realize the value of the associated invention and gain patent-mediated rewards by simply "selling" the patent through an assignment of patent rights to another party. In such a transaction, the value paid for a patent will depend largely on the projected value of the patented technology to users and the amounts that holders of the patent can therefore expect to charge users for access to the technology. Thus, patent assignments offer a patent holder a means to obtain patent-mediated rewards for producing outlier technologies of substantial value to potential users. In a similar fashion, patent licensing agreements allow a patent holder to realize licensing royalties from users of patented technology with the amount of such royalties again scaled to the value the users realize from such use. In both assignment and licensing arrangements, patent rights are essential means to channel rewards for outlier technologies of value to users back to the originators of those technologies. Absent patents, there would be nothing to transfer in patent assignments and nothing to license in patent licenses.

2. Assisting Innovators in Pursuit of Additional Outlier Technologies

Rewards channeled by patents back to originators of outlier advances (both individuals and organizations) ensure that the originators are strengthened and better enabled to conduct further rounds of innovation efforts. This strengthening is important because the innovators involved have already proven that they are capable of producing outlier advances that qualify for patent rights and that serve widespread public interests. The issuance of the patents governing their rewards confirms their ability to generate non-obvious advances and their receipt of significant patent-mediated rewards confirms that the market demand and user needs addressed by their previous patented technologies were substantial.

By selectively strengthening previously successful producers of outlier advances, patent interests leading to commercial rewards tend to encourage the production of more outlier advances from the same innovators. Strengthening innovative organizations may be particularly important as revenues generated from past patents will allow several types of future improvements in research. Greater economic resources can establish an economic cushion that will allow an organizational innovator to survive more instances of research failure – that is, to endure a substantial error rate on the way to the discovery of an additional outlier advance with public significance. Greater resources can also permit a previously successful research organization to invest more in research infrastructure or to recruit more extensive (or better paid) research staffs, thereby increasing the quality and scope of research results achieve in a given time.

3. Avoiding Dysfunctional Strengthening of Non-Innovative Free Riders

Patents also ensure that successful outlier advances do not become sources of rewards to non-innovators that are unlikely to originate additional outlier technologies in future rounds of technology evolution. Absent patent protections ensuring that the competitive benefits of successful outlier technologies flow to the originators of those technologies, free riders witnessing the apparent popularity of new technologies would simply incorporate these technologies in their products and gain substantial fractions of the market rewards for bringing the technologies to the public.

Market rewards captured by free riders would create adverse incentives for technology evolution – they would strengthen entities that were not innovators but rather just copiers of technologies developed by others. Rewards to free riders adopting new outlier technologies would benefit parties lacking any evidence of their skill or willingness to generate further outlier advances and without any proven track record of success in managing the resource allocations and research efforts needed to identify and develop new outlier technologies. At the same time, rewards to free riders would tend to hurt innovators that demonstrated their willingness to be risk takers in the search for outlier technologies and that invested large amounts in research and technology development. These successful innovators would be differentially disadvantaged by rewards to free riders as the innovators would need to cover the costs of technology development efforts before making any profits with a new technology while free riders would not be similarly hindered and would not reduce their profits by technology development expenses.

A system giving free riders rewards for delivering technologies they did not originate and develop would discourage others from the search for new outlier technologies; patent rights help to prevent this result by ensuring market-driven rewards to successful originators of outlier technologies over revenues available to those who merely copy discoveries of others and seek to produce profits without innovation.

IV. Improvements in Patent Laws to Enhance Technology Evolution

The analysis to this point has described existing patent law impacts on technology evolution. Changes in patent laws can improve these impacts. This section presents a normative account of possible changes in patent laws aimed at expanding the scope and degree of patent impacts on technology evolution. Discussions of potential patent law changes are organized around the same points of patent influence noted earlier in this article – that is, changes in patent laws aimed at generating more outlier technologies, changes promoting effective market testing of outlier technologies, and changes strengthening innovators capable of producing more outlier technologies. Potential changes are presented here only in brief sketches meant as starting points for further articulation, consideration, and analysis as possible means to enhance technology evolution.

A. Changes to Generate More Outliers

Changes in patent laws can promote the creation of greater numbers and broader types of outlier inventions and thereby increase the range of inputs to technology evolution. Changes with these types of impacts include expansions in patentable subject matter and alterations in tests for invention non-obviousness.

1. Broadening Patentable Subject Matter

Patentable subject matter standards define the categories of human-created advances that are influenced by patent incentives.[89] By expanding the scope of patentable subject matter, patent law changes can also broaden the types of outlier advances incentivized as inputs to technology evolution processes. By providing more diversity of approaches for adoption and future innovation, the formulation of more outlier designs of new technological devices and processes will be valuable across all types of devices and processes governed by technology evolution. Consequently, more outlier designs incentivized via more inclusive patent incentives will also be valuable across the full range of technology evolution processes. The ideal scope of patentable subject matter from this perspective will be all types of technology advances that are capable of selection and change through technology evolution processes. More outlier advances realized through patent incentives applied across this range of discoveries should

[89] *See* 35 U.S.C. § 101; *Alice Corp. v. CLS Bank International*, 573 U.S. 208 (2014).

enhance technology evolution by incorporating more alternative designs for testing and eventually produce more (and more varied) technology designs for public access and use.

Technology evolution tends to advance designs that vary in sufficiently defined ways for the variants to be tested for functionally superior features and for the best variants selected through such testing to be replicated for broad adoption and use in further evolutionary improvement.[90] Patentable subject matter should include all advances with these features. Specifically, patentable subject matter should be recognized in any advance that is complete enough and described in sufficient detail in both its operative elements and functional results to support evaluation in commercial development and market testing processes. The functional results produced by the advance should have at least some immediate practical utility to users as this will produce potential value to invention users and trigger market testing evaluations. Mere useful ideas will not be enough as they will not, of themselves, produce useful results; when applied to produce tangible real-world results with practical value, the same ideas may be patentable subject matter. Advances described with sufficient particularity to define a specific item or process which produces a useful, concrete, and tangible result will be capable of meaningful evaluation in market testing processes and should be recognized as patentable subject matter.[91]

2. Changes in Non-Obviousness Standards

Non-obviousness standards limit patent rights and incentives to types of inventions that are beyond the range of creativity that would have been obvious to persons of ordinary skill in the fields of the inventions.[92] These standards effectively divide inventions into two subsets: non-obvious inventions that are given the special boost of patent incentives implemented through usage controls derived from patent rights and other obvious inventions that are free for all to use in the competitive production of new products and services. In considering changes in non-obviousness standards to better promote technology evolution, the key question is what types of advances should be given the special evolutionary boost of patent protections and incentives in light of both the invention creation and control implications of patent protections.

One useful approach would be to apply non-obviousness standards to offset technology evolution barriers – that is, to treat as non-obvious and in need of patent incentives those inventions that are most likely to otherwise be omitted from technology evolution processes. Inventions that are realized but never publicly disclosed or never brought to market testing and public attention are much like inventions that were never made for purposes of technology evolution. Such "forgotten" inventions are unlikely to serve public interests and unlikely to form the basis for further evolutionary improvements in technologies. Whatever their merits in

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[90] *See* text at Section II(C), *supra.*
[91] *Cf. In re Alappat,* 33 F.3d 1526, 1544 (Fed. Cir. 1994) (en banc) (Judge Giles Rich, writing for the court, indicates that patentable subject matter is present in an advance constituting "a specific machine [used] to produce a useful, concrete, and tangible result."), *abrogated in In re Bilski,* 545 F.3d 943, 959-960 (Fed Cir. 2008)(en banc).
[92] *See* 35 U.S.C. § 103; Graham v. John Deere Co., 383 U.S. 1, 17 (1966).

expanding knowledge in some ideal sense, these forgotten inventions do not contribute to the cumulative increases in technology functionality achieved through technology evolution.

To expand the innovation inputs to technology evolution, tests for non-obviousness should be crafted to ensure that inventions which are unlikely to be revisited by additional innovators should generally be treated as non-obvious outliers worthy of patent protections and incentives. The interpretation of non-obviousness tests this way will have two implications. First, the availability of patents should incentivize the creation of more of these otherwise rare advances. Second, the increased attention given such advances due to their surrounding patents will help to ensure that the advances are not lost in subsequent technology development. Patents will ensure disclosure of the advances (via published patent applications and patents) and promote consideration of the advances for market testing (due to their enhanced value as protected by patent rights). Patent rights and incentives, as adjusted by non-obviousness standards, can be tailored to offset the low likelihood of reinvention of some advances and to bring more rarely realized inventions into technology evolution.

To help rarely repeated inventions from being lost, inventions should be considered non-obviousness if the advances were unlikely to emerge from multiple sources at the time they were created by a patent applicant – that is, if it is unlikely that an invention under consideration for patenting would have been reinvented by others within a reasonable period.[93] Standards for evaluating non-obviousness should focus explicitly on the likelihood of rediscovery of advances as the touchstone of non-obviousness determinations. Any grounds indicating that it was unlikely other parties would regenerate a particular innovation should be strong evidence that the innovation was non-obvious and in compliance with this requirement for patent protection. Potential grounds for establishing a low likelihood of reinvention – and, hence, the non-obviousness of the invention under the proposed standard – would include the fact that few persons (other than the inventor seeking a patent) had the skills, non-public knowledge, or motivation needed to predict the probable success of the invention in achieving its targeted functionality and to follow through on developing the invention a second time.

Non-obviousness will be clear in several types of circumstances under this standard. Designs assembled accidentally will frequently depart from lines of predictable success since there will have been no design logic or prediction of success underlying how they were

[93] An invention will usually be obvious to persons of average skill if technical knowledge in a field is complete enough to make the technology change reflected in the invention predictably successful in realizing the functionality targeted by the invention. Predictable success makes the new design an obvious choice and one that someone other than a present inventor is likely to try again. Non-obvious inventions, by contrast, are advances that are unlikely to be pursued by the bulk of persons in a technical field because their ordinary or less-than-ordinary skills would not give them reasons to think the new invention designs would achieve the type of functionality realized by the designs. Non-obvious advances which are unlikely to be reproduced by multiple parties will either stem from the work of a few highly talented parties in a field with more than ordinary skills and design insights or from happy accidents of discovery where inventions are first constructed accidentally without any predictions of success.

assembled. The resulting invention will be non-obvious due to the lack of any grounds to expect that it would achieve functional success until its assembly and track record in use proved its functionality.

A second situation where non-obviousness should easily be shown involves inventions made with research findings or bodies of technical knowhow only possessed in confidence by a few parties and not available to broad ranges of parties in the relevant technology field. Absent access to this private knowledge, persons with ordinary skills in the field would have no reason to predict the likely success of an advance with design elements derived from the new knowledge. Advances produced with this private knowledge are outliers beyond the invention capabilities of the general community of specialists in the relevant field. Patent incentives can beneficially bring these otherwise concealed advances to public attention and use. Without patent rights the private discoveries may stay secret and be neglected (thereby benefitting neither the public nor the community of technical specialists interested in the field) or they may be commercialized as trade secrets with some of their benefits reaching the public but none of their design details reaching and enhancing subsequent technology designs.

These are but two examples of the ways that evidence suggesting a low likelihood of duplicate invention can be used to interpret and apply non-obviousness standards in patent analyses. Tailoring non-obviousness tests to the likelihood of the rediscovery of new designs brings patents to bear where they are most needed (because the inventions involved may otherwise be lost to technology evolution and, ultimately, lost to the public) but avoids patent rights and invention use limitations where lines of technology development and disclosure are likely to proceed without special patent incentives through the innovation efforts of persons of average skills. In this way, non-obviousness standards based on the likelihood of reinvention provide narrowly targeted patent boosts to evolutionary processes while leaving other forms of technology change governed by high likelihoods of multiple discoveries unhindered by patent rights and restrictions.

B. Changes to Promote Market Testing

Patent law changes aimed at improving market testing of advances should ensure that patents promote the types of information disclosures needed in market testing and that the rights afforded by patents do not block market testing of patented advances. This subsection explores both these types of changes.

1. Changes to Define and Disclose Invention Features

Improved patent standards should include invention definition and disclosure requirements that ensure patent applicants develop and supply types of information needed in market testing of patented advances. Relevant changes will include revisions in utility, specification, and written description requirements imposed under United States patent laws.

Revised utility standards[94] can ensure that patent applicants are compelled to disclose not only some minimal practical utility resulting from use of an invention[95] but also variations in utility known to the applicant (at the time of patent application submission) for alternative designs of an invention, changes in operating conditions, and differences in operating applications. Features of inventions known to applicants to hinder the functionality or practical utility of inventions should also be required to be disclosed. These types of enhanced disclosures will aid parties in assessing whether there is commercial potential in further product development based on patented advances and in determining whether products based on the advances are likely to be worth pursuing to large-scale production and market testing.

Improved specification standards can expand present requirements of enabling disclosures of sufficient information to allow parties other than an inventor to replicate an invention.[96] Enhanced specification standards might require disclosures of additional information on the functional implications of various design modifications or alternatives insofar as these are known to a patent applicant at the time of filing an application. Also, any results of functional testing of an invention – either alone or in comparison with another device for performing similar tasks – should be disclosed if known to the applicant. These sorts of specification disclosures will help parties other than the inventor not only duplicate a patented advance but also understand the potentially valuable features of its operation and to take the latter into account in market testing analyses.

Written description standards[97] should be enhanced to increase the amount of information required to be disclosed about individual invention elements. Any information known to an applicant about acceptable substitutes for a particular element should be disclosed, as well as the functional implications of making the substitutions (including

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[94] Inventions must possess practical utility to qualify as useful processes, machines, manufactures, compositions of matter, or improvements thereof capable of patenting under the United States patent laws. 35 U.S.C. § 101.

[95] Present utility standards require a patent applicant to disclose at least some practical benefit from use of an invention. *See Brenner v. Manson,* 383 U.S. 519, 534-35 (1966) (holding that a patentable invention must have specific benefit to the public in the current form of the invention). Utility that is demonstrably superior to other means of achieving similar functional ends is not a requirement for patenting an invention. Whether the utility provided by a patented invention is superior to substitutes is a matter for resolution via competition between patented and unpatented products in the relevant marketplace. To qualify for a patent, an invention must have the type of practical utility that buyers and sellers might evaluate in commercial markets. Utility in furthering abstract or philosophical analyses is not enough as "A patent system must be related to the world of commerce rather to the realm of philosophy…." *Id.* at 536 (quoting *Application of Ruschig*, 343 F.2d 965, 970 (1965) (Rich, J.).

[96] Present specification standards require that:

> "The specification [portion of a patent application] shall contain a written description of … the manner and process of making and using [the invention claimed for patenting], in such full, clear, concise, and exact terms as to enable any person skilled in the art to which it pertains, or with which it is most nearly connected, to make and use the same, and shall set forth the best mode contemplated by the inventor or joint inventor of carrying out the invention."

35 U.S.C. § 112(a).

[97] Existing written description standards require that a patent application adequately describe an invention claimed for patenting. *See* 35 U.S.C. § 112(a).

advantages and disadvantages in the operative features of the element involved and the overall invention). The objective of these enhanced written description requirements will be to obligate a patent applicant to disclose all that he or she knows about the functional operation of invention elements including the implications of changes or substitutions in invention elements.

2. Changes to Ensure Market Testing

A patent holder can refuse to develop and market products based on a patented invention[98] – perhaps to protect revenues from continued sales of earlier products that would be displaced by the patented alternatives. Such a blocking action can foreclose market testing of a patented invention for the duration of the applicable patent rights. Patent rights used this way will isolate the patented "traits" of an advance from key evolutionary developments, preventing their adoption in products and further evolutionary improvement. The isolated traits will also fail to influence surrounding competition among produce suppliers and the welfare of parties who might have benefitted from the patented advances. Unavailability of the patented features may spur work around innovation that produces other, non-infringing means for achieving the same functionality as the blocked features. However, the patent-suppressed features will be unavailable, delaying both public benefit from the features and associated technology evolution for the duration of the relevant patents.

One way to avoid this result will be to apply working requirements to issued patents. Under this approach, if products with a patented feature are not made available by a patent holder or a licensee chosen by the patent holder, a party desiring to produce products with the patented feature could force the patent holder to issue a corresponding license at a reasonable royalty fee. The availability of production under such a forced license would ensure that either the patent holder or a licensee would have the opportunity to develop and commercialize attractive patented products and present these products for market testing. This opportunity would lessen the chance that a patented advance with features desired by the public would be suppressed via negative patent rights enforcement.

C. Changes to Strengthen Successful Technologists

Changes in patent laws can also help to ensure that highly successful patented technologies which are widely adopted by the public produce significant benefits to the inventors of the technologies, thereby aiding these successful technologists in their subsequent innovation efforts. Some present arrangements – such as patent royalty splitting terms in academic patent assignment agreements – already channel some of the gains from successful technologies to invention originators. However, patent standards might better guarantee

[98] Generally, a patent holder is entitled to prevent other parties from making, using, offering to sell, selling, or importing a patented advance. *See* 35 U.S.C. § 271(a). However, there is no requirement that the patent holder produce a patented advance or license others to do so.

rewards to the parties that generate patentable technologies with widespread impacts in meeting public needs.

To ensure the channeling to inventors of significant returns from commercially successful inventions, it may be useful to reserve to inventors an inalienable equitable interest in the patents the inventors generate. The equitable interest would obligate a patent holder to make a specified royalty payment to an inventor out of profits derived from a patented advance. The rights to payment retained by inventors under this model would be small (addressing, say, 1 percent of patent returns) and the rights held by the inventors would not extend to any control over patent ownership or licensing. The interests of inventors would function like liens on real property, restricting use of associated patents in a specific way (i.e., requiring legally defined payments upon profitable returns on the patents). This type of guaranteed reward from highly useful and popular technologies would ensure that parties responsible for originating significant advances received substantial feedback benefits, thereby enhancing the subsequent research capabilities of the successful inventors and increasing the chances they will repeat their success by producing other outlier technologies of substantial usefulness to the public.

D. Changes Lowering Technology Evolution Barriers

Patent rights can serve as barriers to technology evolution even where a patented technology is produced during a patent term and thereby made available to the public. Technology evolution will still be hindered if a patent holder restricts the reuse of a patented invention in improved and redesigned technologies.

The evolutionary development of some new technologies will be path dependent in that reuse of particular base technologies will be needed to implement improved technology designs. Where patents on base technologies preclude this type of reuse and there is no path forward in a line of technology evolution without the restricted technology, patent rights may be a significant impediment to technology evolution.

Evolutionary responses to such restrictions may take two possible paths. One will emphasize technological alternatives to the patent-restricted technology. A design around approach may develop an additional means to provide the same sort of functionality as the blocked technology and further evolution can proceed via this alternative path (unless it too is blocked by relevant patents). However, alternative lines of technology change not involving the restricted technology may not work or may only produce alternative functionality that is far inferior to that available via the restricted technology.

The second possible response to patent-imposed blockage of improvements is evolutionary stagnation for the period of patent enforcement. If no efforts to design around a patent-restricted technology are made or the efforts produce poor results, technology evolution along the lines of the patented technology may just stagnate until the relevant patents lapse and free use of the formerly blocked technology can support further evolutionary development and testing. Technology evolution may then resume in a normal manner, but with a delay of years that may have cost the public significant amounts in delayed utility of improved inventions.

Changes in patent law standards can decrease the chances of patent-imposed blockages to technology improvement and associated restrictions on technology evolution. Two types of changes would be desirable: first, changes that provide parties enhancing patented technologies with unhindered opportunities to understand the market value of their discoveries and, second, changes that will compel patent holders of highly popular technologies to license the use of those technologies as the basis for further evolutionary changes and improvements.

Changes to expand information gathering opportunities for persons improving patented technologies would include an expanded interpretation of the experimental use exception to patent infringement liability.[99] This exception should be broadly interpreted to protect all attempts to design patented technology improvements and to test those improvements commercially on a limited scale involving de minimis market penetration and profit generation. The experimental use exception should allow, without the threat of patent infringement liability, the generation within commercial enterprises of workable and perfected examples of new technologies derived from patented base technologies. Some limited testing with consumers of these patented technology variants should also be allowed, including product sales aimed at characterizing user impressions of the variants and market demand for products based on the variants. This type of testing will inform parties who have produce new designs based on patented technologies about the probable popularity and commercial value of the enhanced technologies. With information on the probable commercial value of a variant of a protected technology, the originator of the variant can try to reach a licensing arrangement with the patent holder controlling the base patent. A broad interpretation of the experimental use exception – both as to enhanced product designs incorporating patented elements and related market testing – will be the key to helping innovators gain important knowledge about the importance of their improvements to potential users and the commercial meaning of users' impressions of the improved technology.

Additional changes might be implemented to require patent holders controlling technologies which have gained widespread acceptance to license other parties under terms authorizing the parties to use the successful technologies as the basis for further technology

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[99] Judicial analyses of patent infringement typically exclude actions that entail construction or use of a patented invention for purposes that are solely for amusement, to satisfy idle curiosity, or for strictly philosophical inquiry. These types of actions are deemed to fall within an "experimental use" exception to infringement standards and provide no grounds for patent infringement liability. However, under current standards, the scope of the experimental use exception is quite limited. Actions that are undertaken for business purposes are not seen as instances of experimental use and would, therefore, provide grounds for infringement liability. *See, e.g., Madey v. Duke University,* 307 F.3d 1351, 1360-63 (Fed. Cir. 2002), *cert. den.,* 539 U.S. 958 (2003). Hence, the development of products based on a patented invention with the purpose of selling those products in commerce and the offering of such products in marketplaces for the purpose of market testing of demand for the products are highly likely to be seen as actions having business purposes and providing grounds for patent infringement liability under present standards.

variation and development. Currently, a voluntary counterpart of this process operates in some technology areas through standard setting processes. Patent holders, as a condition of having their technologies included within standards governing widespread uses of technologies, agree to license the patented technologies on fair and reasonable (FRAND) terms.[100] Where these standard setting arrangements prevail, no further action may be needed to ensure that the patented technologies encompassed by the resulting standards are available for subsequent technology change and evolutionary processes.[101]

However, where a patent holder refuses to be involved in a standard setting process or where such processes do not exist, the presence of patent rights blocking further advances in a line of technology may severely limit technology evolution in a specific area. Under circumstances involving widespread adoption of a patented technology by numerous users evidencing extensive interest and benefit from the base technology involved, compulsory licenses under FRAND terms should be imposed on the patent holders who resist licensing on such terms voluntarily.

Several alternative mechanisms might be adopted for imposing these sorts of compulsory licenses. A restrictive version of the licenses might imposed only through government action based on public officials' findings of special public interests in the development of particular technologies (making the imposition of compulsory licenses a direct counterpart to the government imposition of eminent domain proceedings against real property holders to dedicate specific properties to public purposes). A more broadly applicable mechanism might grant private parties the right to force patent holders to grant licenses provided that the parties established widespread usage of a technology suggesting that diverse improvement efforts would probably be in the public interest and that exceptions to normal patent rights in the form of compulsory licenses are specially justified to promote technology evolution. The objective of these compulsory licensing arrangements, however implemented, would be to ensure that patent rights do not bottle up evolutionary change concerning patented technologies. Where voluntarily created licensing arrangements do not permit new evolutionary modifications to popular patented technologies to be developed, market tested, and widely adopted, compulsory licensing terms permitting these key evolutionary steps should be imposed to allow evolutionary changes in technologies to proceed.

V. Conclusion: Advancing Technology Evolution

Evolutionary processes drive technology change. Advances are produced, tested in competition for adoption with past technologies performing similar tasks, and the technologies proving superior in the eyes of users and gaining widespread use serve as platforms for further

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[100] *See, e.g.,* Aimee N. Soucie, UNFAIR COMPETITION AND THE ITC §7:18.

[101] A patent holder's agreement with a standard setting organization to license standards essential patents on FRAND terms establishes a contract to this effect between the patent holder and the organization. Parties seeking a license are third-party beneficiaries of this contract and can seek enforcement of the contract as such. *See, e.g., Microsoft Corp. v. Motorola Inc.*, 696 F.3d 872, 878, 884 (9th Cir. 2012).

rounds of evolutionary change and testing. Through repetitions of these evolutionary cycles, technology designs change to better serve the needs of the public even as those needs shift over time. This matching of technology solutions to public needs proceeds without any overarching direction – without rational design guidance. Technology evolution is guided by the "blind watchmaker"[102] of selection to advance the most effective technologies of the moment, presenting these to the public for both present use and future improvement.

Patent interests alter these important evolutionary processes to emphasize and advantage technology advances that depart materially from existing knowledge in their fields and are consequently outliers among new technology designs. Increased interest focused on outlier designs by the promise of patent rewards for technology adoption encourages the creation of more outlier designs and the testing and public promotion of more outlier designs within technology evolution processes. Patented outlier technologies that serve significant public interests can generate substantial rewards to technology originators that can strengthen these successful innovators in further efforts to produce additional outlier designs with further public benefits. By increasing the range of outlier inventions subjected to technology evolution, expanding commercial interest and market testing of products based on outlier designs, and strengthening innovators capable of producing outlier designs of significance to the public, patent influences on technology evolution can increase the scope and impact of new technology advances brought to public use and benefit.

Recent changes in technology itself – particularly in computer-based technologies supporting artificial intelligence analyses – suggest that methods of technology evolution may shift markedly in the near future. Computer-enhanced testing of physically realized inventions may support rapid perfection of designs by speeding assessments of operating results and user perceptions. Computer simulations of physical inventions (or at least their salient features as seen by users) may permit both the operation and functional results of physical inventions to be predicted and analyzed by computers to determine the likely value of the inventions to potential users. Computers may even aid in the creation of inventions, assisting human inventors as well-informed assistants capable of rapid brainstorming. For instance, such a creative role for computers might involve the specification of the desired functionality of a new invention by a technology designer and computer formulation of the types of invention elements (from whatever technological toolkit the computer could draw upon given the training of its analytic model) that could be means to achieve the desired functionality.[103] This type of

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[102] *See generally* Richard Dawkins, THE BLIND WATCHMAKER: WHY THE EVIDENCE OF EVOLUTION REVEALS A UNIVERSE WITHOUT DESIGN (1986) (arguing that complexity in nature results from unguided natural selection, realizing over time complex biological features as if a "blind watchmaker" had design an intricate timepiece).

[103] The design of useful artifacts through artificial intelligence-based responses to functional requests is not just a future fantasy but rather a present reality in some fields. For example, this type of design is presently used in the field of computer programming. *See* Kevin Roose, *Not a Coder? With A.I., Just Having an Idea Can Be Enough*, N.Y TIMES (Feb. 27, 2025), https://www.nytimes.com/2025/02/27/technology/personaltech/vibecoding-ai-software-programming.html.

invention creation via computer response to functionality requests would shift aspects of the invention definition process from a purely human endeavor into the control of a computer analysis. The computer would then be a central driver of technology design and evolution, with the potential speed and functionality advantages this shift implies.

All of these approaches to enhanced technology change and evolution are likely to strengthen and speed the changes that evolutionary processes are capable of producing in various technology fields.[104] As these (or other) alterations in technology evolution move forward, the interactions of patents with technology evolution should continue to be monitored to ensure that patents remain a positive force enhancing the diversity of new technologies considered for public use, promoting the testing of diverse candidate technologies for public adoption and establishing once outlier technologies as platforms for further technology evolution.

[104] *See, e.g.,* Geoffrey Miller, *Technological Evolution as Self-Fulfilling Prophecy* in TECHNOLOGICAL INNOVATION AS AN EVOLUTIONARY PROCESS 203, 214 (J. Ziman ed. 2000) (noting that computer-implemented searches for new and useful technology designs may expand technology evolution over present processes relying on human creativity producing design variations and economic markets for testing the acceptance of those designs).