DOES THE PATENT SYSTEM PROMOTE SCIENTIFIC INNOVATION? EMPIRICAL ANALYSIS OF PATENT FORWARD CITATIONS

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ABSTRACT

This article sets out to examine the question whether the patent system should continue incentivizing innovation produced by an individual inventive entity in light of the increasing need for collaboration in scientific research and development (R&D).

The patent system views innovation as an individual endeavor. The underlying justifications of the patent system place significant emphasis on the individual inventive entity. This perception is contrary to the way current innovation theories view innovation production and to how scientific R&D is conducted in practice. Current innovation theories view collaboration as central to the innovation process, as the ever growing complexity of scientific R&D dictates the need for scientists to work in collaboration as one researcher or research

* Research fellow at the Haifa Center for Law and Technology. The author thanks Rachel Aridor-Hershkovitz and the participants of the Law and Technology Colloquium, Faculty of Law, University of Haifa, for their helpful comments and suggestions on earlier drafts. The author also thanks Inbar Yasur for her assistance with the data collection, Professor Gregory Graff and Professor Tania Bubela for their help in constructing the data, Pavel Jelnov for substantial help in constructing the models and analyzing the regressions, Tomer Sharon for his constant encouragement and invaluable technical assistance, Professor Niva Elkin-Koren, the author's doctoral advisor, for her invaluable guidance, support and inspiration, and lastly, the editorial board of Albany Law Journal of Science & Technology for their outstanding editorial work. Financial support was provided by the Ministry of Science, Technology and Space 2009 Program for the Development of Scientific and Technological Infrastructures and the Fellowship in Canadian Studies for 2011-2012, sponsored by the Israel Association for Canadian Studies. The views expressed in this paper are purely those of the author's.

organization can no longer hold all the expertise and resources needed to advance science and produce innovation.

This article uses data collected on stem cell research; mainly patent forward citations, as these citations serve as a proxy for the innovative level of the protected technology. As this article further discusses, innovation in the patent system focuses on the individual inventive entity. Nevertheless, the analysis presented here shows that higher rates of innovation are achieved through collaborative R&D activities as opposed to individual endeavors.

The article argues that by focusing on incentivizing the individual inventive entity, the patent system misrepresents how innovation is produced, the same innovation it seeks to promote. It concludes thus with an appeal to policymakers to address the disparity between how the patent system views innovation production and how scientific innovation is produced in practice.

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I. INTRODUCTION

Almost 230 years after the U.S. congress established that the constitutional mandate of the patent system is *"[t]o promote the*

Progress of Science and useful Arts,"[1] the question still remains as to how the patent system should promote scientific progress.

The literature has established that the intellectual property regime favors the individual, whether it is the sole inventor working in her garage, or the lone writer fulfilling her artistic aspirations by the faint light of candle.[2] The romantic notion of the garage inventor, the lone individual who toils in her limited free time, evenings after work and the weekends, who produces a breakthrough that benefits society, unconstrained by the bureaucracy of a large corporate structure or the traditional thinking in a given technological field,[3] fuels the myth of the "individual inventor motif."[4]

American culture loves entrepreneurs: Thomas Edison, Alexander Graham Bell, Henry Ford, David Packard, Steve Jobs, and Bill Gates were all given a place in the hall of fame of individual inventors.[5]

But it is not only the stories of exceptional individuals that keep this myth alive. The patent system itself perpetuates and reifies the myth of the individual inventor. The mechanism by which the patent system achieves its policy objectives, to foster and incentivize invention and innovation, is the allocation of

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[1] U.S. CONST. art. I, § 8, cl. 8.

[2] *See* discussion *infra* Part II.

[3] *See* Christopher A. Cotropia, *The Individual Inventor Motif in the Age of the Patent Troll*, 12 YALE J.L. & TECH. 52, 54 (2009) ("The garage inventor is as American as apple pie. We enjoy stories of independent inventors, working against all odds to provide society with amazing technological breakthroughs.").

[4] This term was coined by Christopher Cotropia. However, the term "individual inventor" is used in the literature to refer to individuals who are sole inventors, as well to small businesses and entrepreneurs. *Id.* at 54 n.2; *see also* Michael J. Meurer, *Inventors, Entrepreneurs and Intellectual Property Law*, 45 HOUS. L. REV. 1201, 1201–04 (2008) (using the terms "small innovative firms," "small business," "small entities," "entrepreneurs," and "inventors" interchangeably); Mark D. Janis, *Patent Abolitionism*, 17 BERKELEY TECH. L.J. 899, 920 (2002) (discussing the impact of proposed "patent law reforms" on both "independent inventors" and "small business").

[5] *See* Meurer, *supra* note 4, at 1202 (discussing American culture's "love" for individual entrepreneurs such as Packard, Edison, Bell, Ford, Jobs, and Gates); *see also* Cotropia, *supra* note 3, at 54 ("The garage inventor is as American as apple pie."). *But cf.* Mark A. Lemley, *The Myth of the Sole Inventor*, 110 MICH. L. REV. 709, 709 (2012) (claiming that the "canonical story of the lone genius inventor is largely a myth", since almost all the great inventions, which were invented by individuals, were in fact invented simultaneously or nearly simultaneously by two or more people working independently of each other).

private property rights to individuals.[6]

The patent system is inherently biased in favor of the individual. This is already apparent in the United States Constitution which defines an inventor as an individual creator, not a firm,[7] in the requirement that patents always be issued to individuals rather than to firms:[8] a patent application must include the name of the inventor for any invention claimed in the application,[9] and in the previous rule of first to invent.[10]

The patent system regards patents as a mean to both motivate individual inventors and protect them from large firms.[11] This is not to say that the patent system does not recognize joint inventors.[12] However, and contrary to what we would expect, it treats joint inventors as an individual entity, referring to them as an "inventive entity,"[13] an "integrated party that is independent from the human beings comprising it."[14]

The emphasis on the individual is also rooted in the justifications underlying the patent system.[15] The inherent individual bias is evident in the incentive scheme, which

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[6] *See* Peter Lee, *Social Innovation*, 92 WASH. U. L. REV. 1, 27 (2015).

[7] Cotropia, *supra* note 3, at 58. It is required in order to identify individual inventors to whom it can assign exclusive rights, although this inventor can of course assign her rights to other entities, such as the firm that employs her.

[8] Lemley, *supra* note 5, at 710.

[9] 35 U.S.C. § 115(a) (2012).

[10] The first to invent regime was amended by the Leahy-Smith America Invents Act, Pub. L. No. 112-29, 125 Stat. 284 (2011) (codified in scattered sections of 35 U.S.C.). However, it remains the law for any patent application filed before March 16, 2013.

[11] *See* Cotropia, *supra* note 3, at 57–58 (stating the importance of the individual inventor is "infused throughout much of the history of the United States patent system," and that the "main goals of the patent system should be to assist, and in some ways protect, the individual inventor"). As this article discusses below, the "individualism" nature of the patent system currently extends to the sole organization as well. *See* discussion *infra* Part III.

[12] 35 U.S.C. § 116(a).

[13] *See* Lee *supra* note 6, at 26 ("A group of joint inventors is termed an 'inventive entity' . . . ."); *see also* 35 U.S.C. § 102(e) (2006). This section of the U.S.C. has since been updated, but it still remains the law for any patent application filed before March 16, 2013. *See* MPEP § 2159.01 (9th ed., Mar. 2014) (noting that the recent amendments to 35 U.S.C. §§ 102 and 103 "do not apply to any application filed before March 16, 2013").

[14] *See* Lee, *supra* note 6, at 26; *see, e.g.*, *In re* Bass, 474 F.2d 1276, 1277 (C.C.P.A. 1973) (treating a three-person group as an inventive entity distinct from its constituent members).

[15] Lemley, *supra* note 5, at 710.

underscores the identification of the individual patentee for the purpose of allocation of rights.[16] I elaborate in this point in Part III.

Before proceeding, several terminological and methodological notes are in order. A distinction must be made between invention and innovation. Generally speaking invention refers to a technical achievement, developing a new technology, whereas innovation is the culmination of all the processes including the development and commercialization of an invention.[17] Economic growth is fueled by innovation.[18]

The common definition of innovation activity used by economists is provided by the Organization for Economic Co-Operation and Development's (OECD) Oslo Manual:

> Innovation activities are all scientific, technological, organisational, financial and commercial steps which actually, or are intended to, lead to the implementation of innovations. Some innovation activities are themselves innovative, others are not novel activities but are necessary for the implementation of innovations. Innovation activities also include R&D that is not directly related to the development of a specific innovation.[19]

Invention is defined by the OECD's Bogata Manual as the output of basic and/or applied research and development (R&D) activities.[20] Commercialization activity is mainly based on

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[16] *See* Lee, *supra* note 6, at 27 (stating that the allocation of property rights is the focus of the patent system and that this system is most effective when such rights are allocated to "a single owner rather than a diffuse group among whom rents must be split.").

[17] *See id.* at 4 (defining "innovation" and "invention"); *see also* F. Scott Kieff, *Property Rights and Property Rules for Commercializing Inventions,* 85 MINN. L. REV. 697, 707–09 (2001) (providing a further discussion of the difference between invention and innovation).

[18] *See* ORG. FOR ECON. CO-OPERATION & DEV., PATENT MANUAL: USING PATENT DATA AS SCIENCE AND TECHNOLOGY INDICATORS 11 (1994) [hereinafter OECD, PATENT MANUAL], *available at* http://www.oecd.org/science/inno/2095942.pdf ("Technological change and innovation are important factors for productivity and competitiveness . . . .").

[19] ORG. FOR ECON. CO-OPERATION & DEV., OSLO MANUAL: GUIDELINES FOR COLLECTING AND INTERPRETING INNOVATION DATA 47 (3d ed. 2005) [hereinafter OECD, OSLO MANUAL], *available at* http://www.oecd.org/innovation/inno/oslomanualguidelinesforcollectingandinterpretinginnovationdata3rdedition.htm.

[20] ORG. FOR ECON. CO-OPERATION & DEV., BOGOTA MANUAL: STANDARDISATION OF INDICATORS OF TECHNOLOGICAL INNOVATION IN LATIN AMERICAN AND CARIBBEAN COUNTRIES 18 (2001), *available at* http://www.uis.unesco.org/Library/Documents/Bogota%20Manual_eng.pdf. R&D activities also include other outputs, such as modifications of existing techniques. *Id.*

registration of patents.[21] The filing of a patent application thus is an early and essential step in the commercialization process.[22] An entrepreneur is an individual who is involved in all stages of innovation, from invention to innovation, and into the market.[23] In summary, "invention and innovation are distinct; they are often done by different people in different organizations," separated from one another on the innovation continuum.[24]

Scientific research has become an increasingly "corporate" endeavor, as increasingly more scientific work can no longer be performed by a sole inventor.[25] This is especially true in fields such as stem cell research that require access to biological materials and expensive research tools available to researchers-scientists through their employer, the research organization.[26] This type of research cannot be conducted from one's garage.

In line with the distinction between invention and innovation, while the lone scientist is the inventor, the research organization

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[21] *See* Tania Bubela et al., *Commercialization and Collaboration: Competing Policies in Publicly Funded Stem Cell Research?*, 7 CELL STEM CELL 25, 29 (2010) (discussing the importance of patents in the commercialization process, although negatively affecting the degree of collaboration in published research).

[22] *Id.*

[23] *See* JOSEPH A. SCHUMPETER, THE THEORY OF ECONOMIC DEVELOPMENT 74–75 (16th ed. 2012) (discussing the concept of entrepreneurs); *see also* Meurer, *supra* note 4, at 1209 ("Thus, an entrepreneur is an innovator; an entrepreneur starts a new business to commercialize an invention.").

[24] Meurer, *supra* note 4, at 1209. Meurer also provides examples from current events as to who should be considered an inventor, innovator and entrepreneur. *See id.* at 1209–10 (stating that Jobs, Wozniak and Gate are great innovators but Edison and Bell are great innovators and inventors).

[25] *See id.* at 1210 ("Some innovation is accomplished by entrepreneurs, but most is accomplished by large firms."); *see also* SCHUMPETER, *supra* note 23, at 74–75 (arguing that entrepreneurs are rarely sole actors). An indication that science is becoming increasingly "corporate" can be traced as far back as Schumpeter. In his early writings Schumpeter describes the innovation process as carried out by an individual entrepreneur, from invention to innovation to market. *See* JOSEPH SCHUMPETER, CAPITALISM, SOCIALISM & DEMOCRACY 132, 134 (Routledge 2006). However, in later writings he claims that large firms are the major source of innovation. SCHUMPETER, *supra* note 23, at 74–75.

[26] *See, e.g.*, Josephine Johnston, *Intellectual Property and Biomedicine*, *in* FROM BIRTH TO DEATH AND BENCH TO CLINIC: THE HASTINGS CENTER BIOETHICS BRIEFINGS BOOK FOR JOURNALISTS, POLICYMAKERS, AND CAMPAIGNS 93 (Mary Crowley ed., 2008), *available at* http://www.thehastingscenter.org/uploadedFiles/Publications/Briefing_Book/intellectual%20property%20chapter.pdf (discussing the advantages and disadvantages of cloning in reference to patents in the biomedical field).

is considered the innovator. However, where long term relationships such as employment are involved, their interests are usually intertwined, sometimes even identical. For this reason the article uses the term "inventive entity" to denote whether the individual discussed is the inventor and/or her employer, the research organization, depending on the context. The use of this term also stems from the empirical analysis. For the analysis it is necessary to determine whether a patent represents an individual or a collaborative R&D activity. To do so I had to identify the inventors-scientists and their institutional affiliation, the patentee. A patent is considered as the result of an individual endeavor or collaborative activity according to both the inventor's and patentee's identity. For this reason the use of term "inventive entity" suits the purpose of this article. I discuss this at length in Part IV.

While the patent system and its underlying justifications focus on the inventive entity, innovation theories that aim to explain how innovation is produced have long recognized the collaborative nature of innovative activity.[27] Innovation has become the central driver of national and global economic well-being and the competitiveness of nations.[28] This is particularly true with the emergence of the knowledge-based economy. Innovation production has been the focus of scholarly debate since the 1960's,[29] however, collaboration has become the focal of innovation theories only in recent decades.[30]

The concept of cross-organizational collaboration was first

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[27] *See* KANETAKA M. MAKI & VISH KRISHNAN, COLLABORATIVE INNOVATION AND KNOWLEDGE CREATION: THEORY AND TESTING WITH A NATURAL EXPERIMENT IN JAPAN 1 (Nov. 2013), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2374730 ("The growing complexity of industrial research and development has created the need for collaboration . . . .").

[28] *See* OECD, PATENT MANUAL, *supra* note 18, at 11 ("Technological change and innovation are important factors for productivity and competitiveness and have thus become a central topic of economic analysis in most industrialised countries.").

[29] *See* DORA MARINOVA & JOHN PHILLIMORE, MODELS OF INNOVATION, *in* THE INTERNATIONAL HANDBOOK ON INNOVATION 44 (Larisa V. Shavinina ed., 2003) (discussing a comprehensive review of the theories governing innovation production and stating that research in this area began in the 1960's).

[30] *See* Marina Ranga & Henry Etzkowitz, *Triple Helix Systems: An Analytical Framework for Innovation Policy and Practice in the Knowledge Society*, 27 INDUS. & HIGHER EDUC. 237, 238 (2013) (discussing the shift in "[r]ecent decades" to a focal point of interaction between the "institutional spheres" of academia, government, and industry).

introduced into innovation theories in the 1990's as economists began to grasp that the complexity of innovation requires collaboration between organizations.[31] The emergence of the notion of Systems of Innovation (SI) marked the realization that innovation is not an isolated process, but takes place under conditions of collaboration and interdependence among organizations.[32] While SI theory focuses on the firm, the theory of Triple Helix (TH), which emerged at the same time, focuses on the university.[33] TH postulates the central role of universities in the innovation process in increasingly knowledge-based societies.[34] It maintains that innovation is dependent on collaboration between the public, private and academic spheres to create new knowledge that in turn drives the innovation process.[35] Since the 1990's these models have further evolved, focusing on collaboration between more actors.[36] While TH and

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[31] *See id.* (indicating that the concept of the interaction between academia, government, and industry began in the 1990's).

[32] *See* CHARLES EDQUIST, SYSTEMS OF INNOVATION APPROACHES – THEIR EMERGENCE AND CHARACTERISTICS, *in* SYSTEMS OF INNOVATION: TECHNOLOGIES, INSTITUTIONS, AND ORGANIZATIONS 1–2 (1997), *available at* http://www.druid.dk/uploads/tx_picturedb/ds2001-178 (stating that "firms almost never innovate in isolation").

[33] *See* Loet Leydesdorff & Henry Etzkowitz, *The Triple Helix as a Model for Innovation Studies*, 25 SCI. & PUB. POL'Y 195, 195 (1998) [hereinafter Leydesdorff & Etzkowitz, *The Triple Helix*], *available at* http://www.leydesdorff.net/th2/spp.htm (discussing what a Triple Helix is and how it applies to the university and innovation); *see also* Henry Etzkowitz & Loet Leydesdorff, *The Dynamics of Innovation: From National Systems and "Mode 2" to a Triple Helix of University–Industry–Government Relations*, 29 RES. POL'Y 109, 109 (2000) [hereinafter Etzkowitz & Leydesdorff, *The Dynamics of Innovation*] ("The Triple Helix thesis states that the university can play an enhanced role in innovation in increasingly knowledge-based societies."). *See generally* Loet Leydesdorff & Henry Etzkowitz, *The Transformation of University-Industry-Government Relations*, 5(4) ELEC. J. SOC. (2001), *available at* http://www.sociology.org/content/vol005.004/th.html (providing a further discussion of the Triple Helix thesis).

[34] Leydesdorff & Etzkowitz, *The Triple Helix*, *supra* note 33, at 197.

[35] Henry Etzkowitz, *Innovation in Innovation: The Triple Helix of University-Industry-Government Relations*, 42 SOC. SCI. INFO. 293, 295–96 (2003); Etzkowitz & Leydesdorff, *The Dynamics of Innovation*, *supra* note 33, at 111–12; *see also* William P. Boland et al., *Collaboration and the Generation of New Knowledge in Networked Innovation Systems: A Bibliometric Analysis*, 52 PROCEDIA - SOC. & BEHAV. SCI.15, 16 (2012) ("All conceptions of the Triple Helix model involve the state, the market and universities.").

[36] *See, e.g.*, Ranga & Etzkowitz, *supra* note 30, at 238. A discussion of the new theories, derived from TH and SI models, is far beyond the scope of this

SI theories are driven by policymakers, the Open Innovation paradigm, that was developed in the early years of the 21st century, is directed by the firm itself.[37] It is a strategic decision of a firm to incorporate access to external sources of innovations[38] into its business model by establishing collaborations with other organizations.[39] Initiatives such as Open Science[40] and "open research"[41] emerged on the heels of the Open Innovation paradigm, signifying the increased collaborative nature of scientific R&D.

The patent system does not reflect the heightened

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work. *See also* Robert Arnkil et al., *Exploring Quadruple Helix: Outlining User-Oriented Innovation Models* 12–13 (Univ. Tampere, Working Paper No. 85, 2010), *available at* https://tampub.uta.fi/bitstream/handle/10024/65758/978-951-44-8209-0.pdf?sequence=1 (discussing how "[t]he Triple Helix Model has evolved and gone through three different development phases" with the latter stages focusing on "communication within the system" and "hybrid organizations"); Elias G. Carayannis, *Q12 Conference – Quadruple/Quintuple Helix Innovation*, YOUTUBE (June 6, 2013), http://www.youtube.com/watch?v=hwIqwwUM5pI; Elias G. Carayannis & David F.J. Campbell, *Mode 3 Knowledge Production in Quadruple Helix Innovation Systems: Twenty-First-Century Democracy, Innovation, and Entrepreneurship for Development*, *in* QUADRUPLE HELIX INNOVATION SYSTEMS, *reprinted in* 7 SPRINGER BRIEFS IN BUS. 1, 36 (2012) (providing a further discussion of the Triple Helix model).

37 *See* Henry Chesbrough, *Open Innovation: Striving for Innovation Success in the 21st Century*, OPEN MIND, https://www.bbvaopenmind.com/en/article/open-innovation-striving-for-innovation-success-in-the-21-st-century/?fullscreen=true (last visited Apr. 13, 2015) (discussing the development of the Open Innovation paradigm, which is directed by firms).

38 *See* JOEL WEST, DOES APPROPRIABILITY ENABLE OR RETARD OPEN INNOVATION?, *in* OPEN INNOVATION: RESEARCHING A NEW PARADIGM 109, 2 (Henry Chesbrough et al. eds., 2006) (stating that "Open Innovation reflects the abilities of firms to profitably access external sources of innovations" and that such decisions are "the ongoing strategies of individual firms for specific technologies").

39 *See* Wim Vanhaverbeke, *The Inter-Organizational Context of Open Innovation*, *in* OPEN INNOVATION: RESEARCHING A NEW PARADIGM 205, 205 (Henry Chesbrough et al. eds., 2006) (indicating that "companies have to team up with other actors in the business system and build inter-organizational networks to support open innovation.").

40 Open Science is an "Open Access" publisher. OPEN SCIENCE, http://www.openscienceonline.com/home/index (last visited Apr. 15, 2015).

41 *See, e.g.*, AGILE KNOWLEDGE ENGINEERING AND SEMANTIC WEB (AKSW), http://aksw.org/About.html (last visited Apr. 15, 2015). AKSW is a research group "committed to . . . free software, open source[s], open access, and open knowledge . . . ."). *Id.* *See generally* Thomas B. Kepler et al., *Open Source Research — the Power of Us*, 59 AUST. J. CHEM. 291 (2006) (providing a discussion of open source movements).

understanding regarding the role of collaboration in innovation theory and practice as it pertains to science. The well-documented phenomenon regarding the inability of the law to keep pace with technological advances does not explain this disparity.[42] This article maintains and aims to show that the patent system still incentivizes individual innovation although the focus of scientific innovation has shifted to collaborative R&D.

Recent literature regarding the individual nature of the patent system serves as the theoretical framework of the article.[43] The literature is theoretical and centers mainly on the cumulative and social nature of innovation (these two terms are at times intertwined) and the problems they pose with regard to patent rights allocation, for example allocation of rights between original inventor and follow-on inventors.[44] This article will focus on a certain attribute of the social nature of the innovation process, specifically scientific R&D collaboration, and will provide empirical evidence to support the claims it makes.

This article seeks to examine the question whether the patent system should continue to incentivize innovation produced by an individual inventive entity, given the increasing need for collaboration in scientific R&D. It focuses on the promising field of stem cell research and provides empirical data to support its claims. It draws on the notion that the technological impact of a patent can indicate its innovative value.[45] It does so by analyzing patents and patent applications, filed in the United States Patent

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[42] *See, e.g.*, Meurer, *supra* note 4, at 1207 (discussing the lack of protection for small businesses in IP and antitrust law in contrast to Europe which "openly fret[s] about how to reform their patent law to promote small business").

[43] *See* Lemley, *supra* note 5, at 710 (discussing how the notion of the lone inventor permeates throughout American history and culture); *see also* Ofer Tur-Sinai, *Beyond Incentives: Expanding the Theoretical Framework for Patent Law Analysis*, 45 AKRON L. REV. 243, 258–60 (2012) (indicating that the well-known labor theory of John Locke is centered on the individual and has been influential on the patent system and property rights in general); Janis, *supra* note 4, at 920 (discussing the impact of proposed "patent law reforms" on both "independent inventors" and "small business"). *See generally* Lee, *supra* note 6.

[44] *See* Lemley, *supra* note 5, at 711–12 (stating that the current patent system focuses on the individual inventor, which is problematic because most inventions today are the product of collaboration).

[45] *See* Manuel Trajtenberg, *A Penny for Your Quotes: Patent Citations and the Value of Innovations*, 21 RAND J. ECON. 172, 184 (1990) (finding that "patent citations may be indicative of the value of innovations . . .").

Office (USPTO), by Israeli actors operating in the stem cell field.[46] These data are unique as they provide the opportunity to analyze an entire industry, not only a sample.

This article proceeds in four Parts; Part II presents the complex notion of collaboration. The collaborative attribute of scientific R&D is reviewed and the definition of "collaboration" used throughout the article is presented. Part III reviews how the patent system regards innovation production and discusses the underlying justifications for the way it fosters innovation. Part IV presents the empirical analysis: the research question, the methodology of patent forward citations, the data and analysis results. Part V provides a short summary and discusses the ramifications.

II. THE COLLABORATIVE NATURE OF SCIENTIFIC RESEARCH & DEVELOPMENT

The purpose of this Part is threefold. First, to show that despite the central place collaboration has gained in the innovation production discourse, there is still no accepted definition. Its context usually determines its meaning. Second, since this article focuses on a scientific field, stem cell research, a discussion of how collaboration has become a widespread practice in scientific activity is presented. The Part concludes with the definition of the term collaboration used in this article.

A. The Many Faces of Collaboration

Collaboration is an intricate term with many definitions and similar terms used interchangeably by diverse scholars in different disciplines and in a variety of contexts. Frequently used terms in the literature include "alliance," "cooperation," "coalition," "coordination," "network," "joint venture," "clusters," "consortium" and "public-private partnership (PPP)."[47] As if this long list of coincident terms is not enough, collaboration also

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[46] *See* discussion *infra* Parts IV.A–B.

[47] Although the terms are grouped here into one long list, they can be roughly divided into two main groups: normative vs. descriptive. *See* Talya Ponchek, Collaboration in Scientific R&D: Patent-Based Indicators Analysis, Evidence from Stem Cell Research in Israel (forthcoming 2015) (unpublished Ph.D. thesis, University of Haifa) (on file with author) (providing a comprehensive discussion of this and a further explanation of the differences).

entails a vast array of activities. These activities differ according to the term used to describe the relationship.

Collaboration can take place at each and every stage of the innovation production chain, from research and development, through manufacturing to marketing.[48] It can also take several forms: infrastructural, formal (or contractual) and informal.[49] Infrastructural collaborations are embedded in national technology and innovation systems and are created especially to support the specific system, for example, public policy support for the creation of PPP or public-private consortia.[50] Formal and informal forms of collaboration are relationships found in industry (also known as the private sector); the two forms differ in the existence, or lack thereof, of an agreement or contract that governs the relationship.[51] The existence of a contract is typical of forms of collaboration where equity is shared, such as a joint venture, but also of collaborations based on a continued commitment to shared objectives without equity sharing, commonly known as a strategic alliance.[52] Informal forms of collaboration are very important to the innovation process in that they take place between peers.[53] This form of collaboration describes the informal know-how trading between peers, which involves routine and informal trading of proprietary information.[54] This knowledge belongs to individuals in research organizations and cannot be easily transferred between them because organizational boundaries serve as "knowledge envelopes."[55]

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[48] MARK DODGSON, TECHNOLOGICAL COLLABORATION IN INDUSTRY: STRATEGY, POLICY AND INTERNATIONALIZATION IN INNOVATION 10 (1993).

[49] *Id.* at 12.

[50] *Id.* at 11–12.

[51] *Id.* at 12–13.

[52] *See* Anders Sundelin, *Strategic Alliances – An Important Part of Most Business Models*, THE BUS. MODEL DATABASE (Aug. 29, 2009), http://tbmdb.blogspot.com/2009/08/strategic-alliances-important-part-of.html (indicating that joint ventures usually result in the formation of "a new and separate legal entity" and that [a] strategic alliance is an agreement between two or more players to share resources or knowledge . . .").

[53] *See* ERIC VON HIPPEL, THE SOURCES OF INNOVATION 6 (1988), (describing "[i]nformal know-how trading . . . [which] involves routine and informal trading of proprietary information between engineers working at different firms . . .").

[54] *Id.*

[55] *See* Changsu Kim & Jaeyong Song, *Creating New Technology Through Alliances: An Empirical Investigation of Joint Patents*, 27 TECHNOVATION 461, 462 (2007). A "knowledge envelope" is when valuable knowledge "belongs to

This Part does not aim to discuss the full range and scope of collaborations, as the topic is broad enough to warrant a separate article. The purpose of this Part is to provide the reader with the understanding that collaboration is not a term that can be used lightly, and that due to its intricate nature a well-defined definition is imperative.

B. Science & Collaboration: You Cannot Have One Without the Other

From a sociological perspective, collaboration is somewhat inherent to the scientific process. Science is a social institution in which advances are vitally dependent on interactions with other scientists.[56] In some fields this may entail the creation of formal collaborations; while in others informal links may suffice.[57]

Scientific research is shaped by social norms of practice.[58] One central element of these norms is openness and data sharing which, through collaboration, leads to transparency.[59] Transparency enables scientists to advance science[60] by allowing

individuals within a firm" and is unlikely to be shared with other organizations. *Id.*

56 *See* THOMAS S. KUHN, THE STRUCTURE OF SCIENTIFIC REVOLUTIONS 1 (2d ed. 1970) (theorizing that "[i]f science is the constellation of facts, theories, and methods collected in current texts, then scientists are the men who, successfully or not, have striven to contribute one or another element to that particular constellation").

57 *See* J. Sylvan Katz & Ben R. Martin, *What Is Research Collaboration?*, 26 RES. POL'Y 1, 14 (1997). The authors discuss how scientists often collaborate on a formal level, but teachers and students are more likely to collaborate on an informal level. *Id.*

58 Noriko Hara et al., *An Emerging View of Scientific Collaboration: Scientists' Perspectives on Collaboration and Factors that Impact Collaboration*, 54 J. AM. SOC'Y INFO. & TECH. 952, 952 (2003). Research collaboration may differ from other types of collaborations "as it is shaped by social norms of practice, the structure of knowledge, and the technological infrastructure of the scientific discipline."*Id.*

59 *See* Arti Kaur Rai, *Regulating Scientific Research: Intellectual Property Rights and the Norms of Science*, 95 NW. U. L. REV. 77, 90 (1999) ("The scientist takes from the cumulative knowledge accumulated by her predecessors and is therefore under a moral obligation to publish any discoveries that build upon the goods that have been given to her."); *see also* David E. Winickoff et al., *Opening Stem Cell Research and Development: A Policy Proposal for the Management of Data, Intellectual Property, and Ethics*, 9 YALE J. HEALTH POL'Y L. & ETHICS 52, 55 (2009) (discussing "longstanding scientific norms regarding open access and dissemination of research results . . .").

60 *See* Sissela Bok, *Secrecy and Openness in Science: Ethical Considerations*,

them to enter the previous layer, their predecessors' knowledge, and such as, collaboration is also consistent with the cumulative nature of science.[61]

Traditionally, science has been perceived as an undertaking conducted collaboratively between researchers sharing data,[62] this is considered to be the "hallmark of modern scientific practice."[63] "Collaboration is often a critical aspect" of fields "dominated by complex problems, rapidly changing technology, dynamic growth of knowledge, and highly specialized areas of expertise."[64] Some will even go as far as to say that collaboration is "a tool of science",[65] or a "scientific value" standing on its own merits.[66]

In the realm of science, collaboration has acquired an additional dimension, the social context of the interaction within the scientific community. Scientific collaboration is understood as an "interaction [that] tak[es] place within a social context among two or more scientists [and] facilitates the sharing of meaning and completion of tasks with respect to . . . mutually shared . . . goal[s]."[67] This collaborative interaction is "defined as

7 SCI. TECH. & HUM. VALUES 32, 32 (1982) ("Unlike other professionals . . . modern scientists have never staked out rationale justifying even limited practices of secrecy. They have held free and open communication to be the most important requirement of their work.").

[61] *See* Rai, *supra* note 59, at 90 (discussing the "communal" nature of science).

[62] *See* KUHN, *supra* note 56, at 176 (describing the communal nature of traditional scientific research). Joint publications and scientific conferences, for example, are forms of traditional data sharing. *See* Winickoff et al., *supra* note 59, at 61.

[63] Jeremy P. Birnholtz & Metthew J. Bietz, *Data at Work: Supporting Sharing in Science and Engineering*, *in* PROCEEDINGS OF THE 2003 INTERNATIONAL ACM SIGGROUP CONFERENCE ON SUPPORTING GROUP WORK 339, 340 (2003). Despite its importance, data sharing is not easy. *See id.* (discussing the difficulties in data sharing).

[64] Hara et al., *supra* note 58, at 952; *see also* Ricardo B. Duque et al., *Collaboration Paradox: Scientific Productivity, the Internet, and Problems of Research in Developing Areas*, 35 SOC. STUD. SCI. 755, 756 (2005) ("The necessity and perceived success of collaboration in basic scientific fields such as high energy physics, the desire of scientists for larger and more complex instruments, and the importance of informal communication to the research process led eventually to a positive valuation of collaboration for its own sake.").

[65] Hara et al., *supra* note 58, at 953.

[66] Duque et al., *supra* note 64, at 756.

[67] Diane H. Sonnenwald, *Scientific Collaboration*, 41 ANN. REV. INFO. SCI. & TECH. 643, 645 (2007).

the *working together*" of researchers "to achieve the common goal of producing new scientific knowledge."[68] This definition lies between two extremes of a possible continuum of scientific collaborations: a weak collaborative activity that involves providing input to a particular piece of research, and a strong collaborative activity that involves contributing directly to the main research tasks over the duration of the project.[69]

The social context of the scientific collaboration is comprised of five dimensions: (1) profession of the participants (people from academia and business);[70] (2) the organizational level of the collaboration - the collaborations are between "individuals or teams, not between firms";[71] (3) the institutional affiliation - the "collaborators are not all members of the same organization";[72] (4) the disciplinary focus;[73] and (5) the geographical focus.[74] These dimensions should be addressed in conceptualizing the definition of collaboration. This is discussed in Part II.C.

The literature includes extensive discussions concerning the need to promote collaboration in scientific R&D.[75] Next I review some of the discussions in a nutshell.

There are situations in which working alone cannot achieve the

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68 CANADIAN COALITION FOR GLOBAL HEALTH RESEARCH, COLLABORATIVE RESEARCH: AN "INDIGENOUS LENS" PERSPECTIVE 1 (2008) (emphasis added).

69 Katz & Martin, *supra* note 57, at 11. It is important to note that Katz and Martin use the term "research collaboration" as opposed to "scientific collaboration," while they state that research is implicitly taken to mean scientific research. *See id.* at 1. Others view "scientific collaboration" as a broader term than "research collaboration" which is more narrowly defined by the scope of the research project to which it refers. This is more a reading between the lines than a substantiated statement. *See, e.g.*, Ivan Chompalov et al, *The Organization of Scientific Collaborations*, 31 RES. POL'Y 749, 750 (2002). I do not find this difference to have any real impact on this article, as the definition of collaboration for the purpose of this work refers to R&D activity as discussed later.

70 Teresa M. Amabile et al., *Academic-Practitioner Collaboration in Management Research: A Case of Cross-Profession Collaboration*, 44 ACAD. MGMT. J. 418, 419 (2001).

71 *Id.*

72 *Id.*

73 Sonnenwald, *supra* note 67, at 645–46.

74 *Id.* at 647.

75 *See, e.g.*, Joan P. Schwartz, *Silence is Not Golden: Making Collaborations Work*, OFF. RES. INTEGRITY (June 2, 2011), http://ori.hhs.gov/silence-not-golden-making-collaborations-work ("[R]esearch collaborations frequently facilitate progress and generally should be encouraged.").

desired ends.[76] These situations include scientific research in fields in which research is more complex and requires more specialized knowledge – more than any single individual or research organization may be expected to possess.[77] Given the increasing scientific and technological complexities, it has become increasingly apparent in recent decades that no one scientist or research institution can conduct most of the scientific R&D on its own.[78] Collaboration enables access to additional or hitherto unavailable expertise, prior knowledge, scarce biological materials, expensive research tools and other capabilities needed to compete in changing markets, etc.[79] "An individual scientist" seldom has "all the expertise and resources necessary to address complex research problems."[80] It is for these same reasons that science has become "corporate" as the high costs of research have become prohibitive for a lone researcher in a garage, and certain fields of research, traditionally considered independent, are now

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[76] *See* Peter Galison, *The Many Faces of Big Science*, *in* BIG SCIENCE: THE GROWTH OF LARGE-SCALE RESEARCH 1, 2 (Stanford Univ. Press 1992) (stating that the "rapid growth of big science" has resulted in the loss of "individual autonomy"); *see, e.g.*, Steve Cropper, *Collaborative Working and the Issue of Sustainability*, *in* CREATING COLLABORATIVE ADVANTAGE 80, 81 (Chris Huxham ed., 1996) (describing an example of many local agencies collaborating on an anti-smoking campaign to make the campaign a success).

[77] *See* Sooho Lee & Barry Bozeman, *The Impact of Research Collaboration on Scientific Productivity*, 35 SOC. STUD. SCI. 673, 673 (2005) ("The increasingly interdisciplinary, complex, and costly characteristics of modern science encourage scientists to get involved in collaborative research."); *see also* Hara et al., *supra* note 58, at 952 ("Collaboration is often a critical aspect of scientific research, which is dominated by complex problems, rapidly changing technology, dynamic growth of knowledge, and highly specialized areas of expertise. An individual scientist can seldom provide all the expertise and resources necessary to address complex research problems.").

[78] Galison, *supra* note 76, at 2; *see also* Bubela et al., *supra* note 21, at 26 (discussing "[c]ollaboration networks").

[79] *See* Katz & Martin, *supra* note 57, at 15 (describing the benefits of collaboration such as "the transfer of knowledge or skills"); *see also* Sonnenwald, *supra* note 67, at 643 ("Scientific collaboration . . . has the potential to solve complex scientific problems . . . ."); Bernard Munos, *Lessons from 60 Years of Pharmaceutical Innovation*, 8 NAT. REV. DRUG DISCOVERY 959, 965 (2009) (indicating that "consolidation" can result in increased output and decreased costs).

[80] Hara et al., *supra* note 58, at 952; *see also* Katz & Martin, *supra* note 57, at 8 (indicating that "escalating costs of conducting fundamental science" is another reason why firms must often collaborate).

becoming more collaborative because of these circumstances.[81]

Even pharmaceutical companies that traditionally held inter-firm based R&D activities now recognize that new drugs will only be developed through innovative partnerships with public research institutions and biotechnology companies.[82] Multidisciplinary collaborations provide "the knowledge, skills and abilities required for the advancement of . . . [science]."[83] The more science-based and complex the scientific research, the more collaboration is required.[84] More important benefits are less duplication of effort and better utilization of resources. For example, collaboration prevents scientists from investing resources only to find that the technology they have been working on so vigorously already exists, having been developed by another research group.[85]

To summarize the discussion so far, scientific progress fuels innovation, and it does so through collaboration. The patent system promotes innovation by commercializing scientific R&D outputs. However, as I discuss further in Part III, science and the patent system hold completely different and opposing views as to how innovation is produced.

C. Conceptualizing "Collaboration"

For the purposes of this article, "collaboration" is defined as

[81] *See, e.g.*, Katz & Martin, *supra* note 57, at 8.

[82] *See* Constance E. Bagely & Christina D. Tvarno, *Pharmaceutical Public-Private Partnerships: Moving from the Bench to the Bedside*, 4 HARV. BUS. L. REV. 373, 376 (2013) (discussing the example of Bristol-Myers Squibb who formed a partnership with "ten cancer research institutes . . . to 'facilitate the translation of scientific research findings into clinical trials and, eventually, clinical practice, as well as advance innovation in drug discovery and development'").

[83] Hara et al., *supra* note 58, at 953.

[84] *See* John Hagedoorn, *Inter-firm R&D Partnership: An Overview of Major Trends and Patterns Since 1960*, 31 RES. POL'Y 477, 480 (2002) (stating that "[m]ajor factors . . . related to important industrial and technological changes in the 1980s and 1990s . . . led to increased complexity of scientific and technological development, higher uncertainty surrounding R&D, increasing costs of R&D projects, and shortened innovation cycles that favor collaboration").

[85] *See, e.g.*, Anders Sørensen, *R&D Subsidies and the Surplus Appropriability Problem* 1 (Copenhagen Bus. Sch., Working Paper No. 17, 2005) (arguing that decentralization results in underinvestment which in turn leads to distortions in R&D such as "knowledge spillovers in research, externalities associated with duplication, and creative destruction").

a*ny activity that leads to joint scientific R&D and results in at least one patent application*. It may be performed by two or more participants that contribute resources and knowhow. Though dimension (1) above dictates that not all the organizations participating in the scientific collaboration can be firms, because this would constitute a different type of collaboration (such as RJV which is considered a firm-firm collaboration),[86] this article included firm-firm collaboration in its definition since, in the case of the stem cell industry, firms are involved in hands-on scientific research.[87] This definition is broad and includes interactions between researchers from the same institution, different institutions, different disciplines and countries. It includes privately initiated and publicly fostered interactions, which may take the form of (1) collaborative research programs or consortia; (2) joint ventures and strategic alliances; and (3) shared R&D production contracts. They do not cover licensing agreements and one-way knowledge transfers such as technology acquisition.

III. INNOVATION THROUGH THE LENS OF THE PATENT SYSTEM

In the previous Part, this article postulated that scientific activity is conducted through collaboration. In this Part, I will examine how innovation production is viewed and incentivized through the patent system.

Several scholars have recently discussed the individual nature of the patent system.[88] Their discussion of individualism acknowledged that innovation is a social process.[89] I wish to draw

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[86] *See* Helena Bukvova, *Studying Research Collaboration: A Literature Rev.*, 10(3) SPROUTS: WORKING PAPERS ON INFO. SYS. 1, 2 (2010), *available at* http://aisel.aisnet.org/cgi/viewcontent.cgi?article=1325&context=sprouts_all (arguing that scientific collaboration "has to include some academic researchers, although non-scientists can also be included"); *see also* Amabile et al., *supra* note 70, at 419 (discussing "cross-profession" collaboration, such as collaboration between business and academia). The authors describe such collaborations as being "between individuals or teams, not between firms." *Id.*

[87] *See* NIVA ELKIN-KOREN ET AL., POLICY ON LEVERING STEM CELL RESEARCH THROUGH INTELLECTUAL PROPERTY (May 2013), *available at* http://www.neaman.org.il/Neaman2011/Templates/ShowPage.asp?DBID=1&TMID=581&LNGID=1&FID=646&IID=10377.

[88] *See, e.g.*, Lemley, *supra* note 5, at 710.

[89] *See* discussion *supra* Part I (explaining that innovation is the interaction of "all processes" leading to the "development and commercialization of an

on this line of thinking and suggest that the individual focused nature of the patent system is incompatible with its purpose of fostering scientific innovation. I will discuss the classical or orthodox justifications for patent protection and examine the explanations as to how the patent system fosters innovation. Five theories are included in the review, divided into two groups: economic justifications embodied in the incentive theory, disclosure theory and prospect theory[90]; and non-utilitarian theories with the attendant labor theory and the personality theory.[91] Though each of these theories raises concerns and elicits criticism, I do not discuss them as they are not the focus of this article. The purpose is to acquaint the reader with the way innovation is presented through the lens of the patent system.

A. Economic Justifications

Traditional analysis of patent systems focuses on economic benefits.[92] The most common justification for the patent system is found in the *incentive theory*.[93] There is universal agreement that the purpose of the patent system is to promote innovation, through the creation of inventions, by granting exclusive rights to the patentee.[94] This is the basic utilitarian purpose of patent system.[95] The underlying assumption is that patent protection of

invention). Though I agree that innovation is a social process, I maintain that they should be using the term invention and not innovation. *See generally id.*

[90] *See* John A. List, *Neoclassical Theory Versus Prospect Theory: Evidence from the Marketplace* 1–2 (Nat'l Bureau of Econ. Research, Working Paper No. 9736, 2003), *available at* http://www.nber.org/papers/w9736 (providing a discussion of the prospect theory).

[91] *See* Kanu Priya, *Intellectual Property and Hegelian Justification*, 1 N.U.J.S. L. REV. 359, 362 (2008) (discussing Hegel's personality theory).

[92] *See* Tur-Sinai, *supra* note 43, at 248 ("[T]he traditional analysis of patent law focuses on the economic benefits of the patent system.").

[93] *See* Eli M. Salzberger, *The Law and Economics Analysis of Intellectual Property: Paradigmatic Shift from Incentives to Traditional Property*, CESIFO CONFERENCE ON LAW AND ECONOMICS, Munich, Ger., May 28–29 (2010), *available at* http://ssrn.com/abstract=1574994 (explaining that "[t]he incentive theory ha[d] been the main Law and Economics paradigm for the analysis of intellectual property until the recent shift to the proprietary paradigm").

[94] Dan L. Burk & Mark A. Lemley, *Policy Levers in Patent Law*, 89 VA. L. REV. 1575, 1580 (2003). Though opinions are divided as to whether the patent system actually achieves its goals. *See id.* at 1580–81 (citing defenders of the patent system, vocal critics, and those who cannot decide whether the system is good or bad).

[95] *See id.* at 1596–97 ("Patent law . . . started from a widely-shared

research output is necessary due to its "public good" attribute, since research output is comprised in part (and sometimes entirely) of non-tangible property.[96] The distinctive characteristics of public good are "non-excludability" and "non-rivalry."[97] It can be used by multiple parties without diminishing its availability and it is almost impossible to exclude others from appropriating it.[98] Put simply, the enjoyment of one person does not exclude enjoyment by others. These characteristics in combination may serve as a disincentive to innovation. Potential inventors would know that once they revealed their breakthroughs to the world other people would be able to take advantage of them for free whereas inventors would not be able to recoup the costs of their innovations. Since appropriating such assets is easy, this leads to "free riders", thus diminishing incentives to invent and innovate.[99] This argument presents the "danger that the pace of technological innovation will fall below socially optimal levels."[100] Potential inventors might "devote their energies to other, more lucrative activities," at the expense of others, causing "society at large [to] suffer."[101] The patent system overcomes these obstacles and promotes innovation by granting

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utilitarian baseline."); *see also* Lemley, *supra* note 5, at 736 (discussing the "incentive that exclusivity provides"); Rebecca S. Eisenberg, *Patents and the Progress of Science: Exclusive Rights and Experimental Use*, 56 U. CHI. L. REV. 1017, 1024–28 (1989) (providing further discussion of the "incentive to invent theory").

[96] Tur-Sinai, *supra* note 43, at 248.

[97] *Id.*

[98] *See* Burk & Lemley, *supra* note 94, at 1580 (stating that the public good is usually "expensive to [develop] but easy to appropriate"); *see also* Nancy Gallini & Suzanne Scotchmer, *Intellectual Property: When is it the Best Incentive System?*, *in* 2 INNOVATION POLICY AND THE ECONOMY 51, 53 (Adam B. Jaffe et al. eds., 2002) (giving the example of information as a public good and stating that inventions are made up of information, as well as tangible parts, and therefore incentives to invent are necessary because a rival only needs the tangible parts but the original inventor needs both the information and tangible parts of the invention).

[99] Lee, *supra* note 6, at 25; *see also* Eisenberg, *supra* note 95, at 1024–25 (discussing the "incentive to invent theory").

[100] William Fisher, *Intellectual Property and Innovation: Theoretical, Empirical, and Historical Perspectives*, *in* INDUSTRIAL PROPERTY, INNOVATION, AND THE KNOWLEDGE-BASED ECONOMY, 37 BELEIDSSTUDIES TECHNOLOGIE ECONOMIE, at 1 (2001), *available at* http://cyber.law.harvard.edu/people/tfisher/Innovation.pdf.

[101] *Id.* at 2. This argument was developed by well-known scholars like Jeremy Bentham and John Stuart Mill. *Id.* at 2 n.1.

the patentee the right to exclude others from practicing the patented invention, thus enhancing incentives to invent while mitigating the market failure.[102] This right is given to the patentee for a limited time,[103] in exchange for her disclosure of the new technology to the public (the *disclosure theory*[104]), thus encouraging the disclosure of inventions that might otherwise be kept secret.[105] During this period the patentee "should be able to cover her . . . [R&D] costs and make a reasonable profit in the

[102] *See* Lee, *supra* note 6, at 25 ("Patents mitigate this market failure by granting exclusive rights, thus enhancing incentives to invent."); Burk & Lemley, *supra* note 94, at 1580 ("[S]uch legal restraints on patentable inventions are justifiable if they offer a net benefit to society, trading the disutility of restricted output and higher prices for the greater social utility of inventions that might otherwise not be produced.").

[103] *See* 35 U.S.C. § 154(a)(2) (Supp. 2013) (granting an inventor exclusivity for a period of twenty years). The limited time (and scope) of the monopoly is also important from an economic point of view. It mitigates the phenomenon of owners setting (usually) a price that will maximize their profits, leading to underuse of innovation, rather than a price, which equals their marginal or average cost of production. Salzberger, *supra* note 93, at 8; *see also* Mark A. Lemley & Carl Shapiro, *Probabilistic Patents*, 19 J. ECON. PERSPECTIVES 75, 75 (2005) (arguing that a patent does not provide absolute exclusion, but rather presents a legal right to try to exclude). However, this limited time monopoly raises concerns regarding its possible consequence of restraints on the patentability of future inventions. *See* Ofer Tur-Sinai, *Cumulative Innovation in Patent Law: Making Sense of Incentives*, 50 IDEA 723, 725 (2010) (explaining that the cumulative nature of innovation dictates the frequent need of inventors to "rely on the discoveries and inventions of previous inventors in order to make their own contribution", and that the potential conflict between the exclusive rights and the need to capitalize on their invention in order to continue developing the technology may result in a chilling effect). Having said that, the concerns regarding access to patentable technology are beyond the scope of this article.

[104] *See* Eisenberg, *supra* note 95, at 1029–30 (discussing the "incentive to disclose" theory). The *Disclosure Theory*, though considered a utilitarian justification, is subordinate to the primary utilitarian justification—the *Incentive Theory*. *Id.*

[105] *See generally* Kenneth J. Arrow, *Economic Welfare and the Allocation of Resources for Invention*, *in* THE RATE AND DIRECTION OF INVENTIVE ACTIVITY: ECONOMIC AND SOCIAL FACTORS 609, 614–16 (Nat'l Bureau of Econ. Research ed., 1962) (discussing problems in resource allocation, specifically information as a commodity). *But cf.* Lemley, *supra* note 5, at 745–46 (explaining that nowadays patent description and claims are worded vaguely and broadly, which prevents future inventors from learning about the protected technology, thus violating the contract between inventor and society, concluding that the justification behind disclosure theory does not support the current patent system).

market . . . [with] her invention."[106]

These incentives to innovate, in the form of allocation of private rights, are most effective if the rewards of exclusivity are bestowed upon a single owner rather than a diffuse group among whom royalties must be split.[107] It is for this reason that the patent system needs to identify individual inventors to whom it can assign exclusive rights. In the realm of scientific research, these rights are usually assigned to the employer, the research organization.[108] Assigning property rights to an individual research organization also relates to the information efficiencies of organizing technological production in markets. As the unit of decision-making capacity in the market is typically an individual or the research organization, this assignment "best enables the market transactions that optimize technological development."[109]

Prospect theory is another theory that provides economic justifications for the patent system.[110] It was developed in light of the fundamental controversy as to the proper scope, availability, and even need for patents in order to optimize innovation; while the basic agreement between inventor and society embodies utilitarian goals, how it should be implemented remains unclear.[111]

Prospect theory is rooted in many of the same economic traditions as the *incentive theory*, but its focus is not on ex-ante incentives to innovate.[112] Instead, it emphasizes *ownership to one patentee* to control R&D and efficiently diffuse it into the market through licensing.[113] Granting "exclusive rights to *individual*

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[106] Tur-Sinai, *supra* note 43, at 248.

[107] Lee, *supra* note 6, at 27.

[108] *See id.* at 26 (stating that "many creations arise more collectively from communal efforts"). While the employer is likely to enjoy the royalties, the employee may enjoy the revenue streams arising from exclusive rights, if there is such an employment agreement between the two parties.

[109] *Id.*

[110] *See* Edmund W. Kitch, *The Nature and Function of the Patent System*, 20 J.L. & ECON. 265, 266 (1977) (providing background on the prospect theory).

[111] *See* Burk & Lemley, *supra* note 94, at 1575, 1599–616 (providing a comprehensive discussion of the five distinct approaches to the proper scope and allocation of patent rights).

[112] *See id.* at 1615–17 (discussing the prospect theory); *see also* Mark A. Lemley, *Ex Ante Versus Ex Post Justifications for Intellectual Property*, 71 U. CHI. L. REV. 129, 133 (2004) ("[P]atents are valuable, not just to create ex ante incentives to innovate, but also because they create property rights . . . .").

[113] *See* Burk & Lemley, *supra* note 94, at 1600–01 (discussing how the prospect theory emphasizes licensure and individual property rights to

patentees enhances social efficiency by allowing the patentee to rationally coordinate the development of a technological prospect."[114] These efficiency gains stem from the fact that "a *single* entity [is] managing a technological resource that would be lost if a diverse group of loosely affiliated individuals all had claims on the invention."[115]

The fundamental economic bases of this approach are the "tragedy of the commons"[116] and "the hypothetical Coasean world without transaction costs."[117] The tragedy of the commons calls for privatization (or commodification) of public goods to ensure the enjoyment of everyone.[118] The most notable example in this context is the greenery which is open for everyone to herd their sheep. People with access to common property overuse it because each individual reaps all of the benefits of his personal use, but shares only a small portion of the costs.[119] The establishment of *individual property rights* prevents these situations. "Kitch's prospect theory strongly emphasizes the role of a *single patentee*

encourage innovation and efficiency); *see also* Kitch, *supra* note 110, at 266 (The patent system seeks to "assure efficient allocation of the resources . . . by awarding exclusive and publicly recorded ownership of a prospect shortly after its discovery."); Robert P. Merges, *Of Property Rules, Coase, and Intellectual Property*, 94 COLUM. L. REV. 2655, 2660–61 (1994) (stating that "the overall goal of intellectual property law is often described in allocational efficiency terms" and "the law would seem to favor allocation of rights to creators . . .").

[114] Lee, *supra* note 6, at 27 (emphasis added).

[115] *Id. Cf.* Harold Demsetz, *Toward a Theory of Property Rights*, 57 AM. ECON. REV. 347, 354–56 (1967) (comparing communal ownership rights with private ownership rights).

[116] Garrett Hardin, *The Tragedy of the Commons*, 162 SCIENCE 1243, 1244 (1968).

[117] Burk & Lemley, *supra* note 94, at 1600. *See generally* R. H. Coase, *The Problem of Social Cost*, 3 J.L. & ECON. 1, 10 (1960) (discussing the theory of a world without transaction costs); *see also* Salzberger, *supra* note 93, at 30–31 ("Coase argued that inefficient legal rules will be bypassed by individuals attempting to achieve efficient allocation of entitlement, but this will happen only when there are no transaction costs.").

[118] *See, e.g.*, Hardin, *supra* note 116, at 1248 (stating that although "[f]reedom [in a commons] will bring ruin to all," the tragedy of the commons can be put an end by relinquishing the freedom in a commons).

[119] *See* Burk & Lemley, *supra* note 94, at 1600 (giving two examples of the tragedy of the commons theory: a lake open to the public that is overfished and common fields that are overgrazed); *see also* Salzberger, *supra* note 93, at 33 (explaining that the tragedy of the commons describes a situation in which an increase in demand in the absence of property rights leads to over-consumption, and the tragedy lies in creating a worse situation for all individuals).

in coordinating the development, implementation, and improvement of an invention."[120] It is supported by the Coase theorem.[121] According to this theorem, "giving *one party* the power to control and orchestrate all subsequent use and research relating to the patented technology should result in efficient licensing . . . assuming . . . that information is perfect, all parties are rational, and licensing is costless."[122] Though this theory has been the subject of criticism,[123] its relevance here stems from the emphasis it puts on *regulating the individual's activity*, while the *individual* may very well be an organization.[124] It is the *individual action* that needs to be regulated to foster innovation, which is comprised of public goods.[125]

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[120] Burk & Lemley, *supra* note 94, at 1603 (emphasis added). *See generally* Kitch, *supra* note 110, at 271–80 (discussing the prospect theory).

[121] *Id.* at 1602.

[122] *Id.* (emphasis added).

[123] *See* Tur-Sinai, *supra* note 43, at 249–50 (stating that Kitch's theory "never gained wide support amongst scholars analyzing the patent system, and it has been the subject of criticism . . .").

[124] *See* Burk & Lemley, *supra* note 94, at 1615 (discussing prospect theory and stating that it "necessarily envisions invention as something down by a single firm, rather than collectively").

[125] *See id.* at 1603–05. The article discusses Kicth's theory, which emphasized the importance of a single patentee in innovation and suggesting that the individual entity needs to have "appropriate incentives to invest in commercializing and improving an invention." *Id.* at 1604. It also states that "information is a public good." *Id.* at 1605. It is important to note here that the current ongoing trend of commercialization of research outputs imposes increasingly high transactions costs to obtain intellectual property rights (IPRs), monitor, enforce, negotiate and license these outputs. The result of the expanded coverage of IPRs and the increased transaction costs is the reduced volume of research that is accessible, de-facto impeding the production of new innovation. *See, e.g.*, Lawrence Lessig, *Free(ing) Culture for Remix*, 2004 UTAH L. REV. 961, 972 (2004) (describing the high cost of obtaining a copyright license in the music industry); *see also* Fisher, *supra* note 100, at 4 (stating that intellectual property rights "are costly to administer). The establishment and maintenance of patent registration systems, the staffing of courts to interpret and enforce entitlements, and the employment of lawyers first to obtain and then to protect entitlements – all of these things consume substantial social resources." *Id.* The author suggests that this system may in some instances "frustrate[e] [invention] altogether." *Id.* This phenomenon of IPRs creating barriers to scientific R&D and innovation is referred to as the "tragedy of the anti-commons." *See* Michael A. Heller & Rebecca S. Eisenberg, *Can Patents Deter Innovation? The Anticommons in Biomedical Research*, 280 SCIENCE 698, 698 (1998). This is closely related to the concerns raised regarding the limited monopoly as mentioned previously. However, empirical literature includes

B. Non-Utilitarian Theories

Economic rationales are not the only possible justifications explaining how the patent system advances innovation by focusing on the individual entity. The deontological-based theories, the *labor theory*[126] and the *personality theory*,[127] fall into the same trap.

One of the main theories used to justify property rights, including intellectual property rights (IPRs), is the labor theory, which is based on John Locke's theory of natural law.[128] From the terminology used by Locke we learn that this theory also focuses on the individual inventor.[129] Locke asserts "that *every person* has a natural right to the fruits of her labor", whether the creation is physical or intellectual.[130] "[W]hatever *a person* has removed out of its natural state and mixed her labor therewith belongs to her."[131] "This right cannot be compromised even if allocating such a right decreases . . . social welfare."[132] "Locke's conclusion that *a person* has a property right in the fruits of her labor follows from his argument that *a person* owns a right to her own body, hence, to the labor of her body, and therefore to anything that results from mixing her labor with common resources."[133] The focus on the individual is even apparent from the further condition specified by Locke for the acquisition of

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evidence that both asserts and rejects the anti-common phenomenon. *See, e.g.*, Timothy Caulfield et al., *Patents, Commercialization and the Canadian Stem Cell Research Community*, 3 REGEN. MED. 483, 483 (2008) (rejecting the anti-common phenomenon and stating that it did not appear to have any effect on stem cell research). *But cf.* John P. Walsh et al., *The Patenting of Research Tools and Biomedical Innovation*, *in* PATENTS IN KNOWLEDGE-BASED ECONOMY 1–3 (Wesley M. Cohen & Stephen A. Merrill, eds., 2003) *available at* http://www.iatp.org/files/Patenting_of_Research_Tools_and_Biomedical_Inn.htm (providing some evidence that IP law has impeded drug discovery, but stating that this is generally not the case).

[126] *See* Tur-Sinai, *supra* note 43, at 257–59 (providing an explanation of the labor theory).

[127] *See* Priya, *supra* note 91, at 362–64 (discussing Hegel's personality theory as it relates to IP law).

[128] *See* Tur-Sinai, *supra* note 43, at 257–59.

[129] *See id.* at 259 (discussing a "laborer" who creates something that is "valuable for society" and is then "morally entitled to a just reward in consideration for such value").

[130] *Id.* at 257 (emphasis added).

[131] *Id.* (emphasis added).

[132] Salzberger, *supra* note 93, at 3.

[133] Tur-Sinai, *supra* note 43, at 258 (emphasis added).

property: the duty to leave enough for others asserts that *one* may prevent others from using her labor product only if there remain sufficient resources in the public domain to allow others to labor and acquire property as well.[134]

"The labor theory can be criticized on various grounds."[135] The most relevant criticism for the purpose of this discussion is that this theory is based on the unrealistic assumption that labor can be attributed exclusively to *a single individual*, whereas scientific R&D is typically conducted in teams comprised of numerous individuals from the same institution, or from different institutions, and "in an environment that provides the laborer-researcher with the necessary tools and opportunity to work."[136] "This makes it difficult to justify the grant of exclusive rights" to work output to the "individual based on the argument that such [output] is the product of her labor."[137]

Another theory that is often used to justify the need for the patent system is *Hegel's personality theory*,[138] as refined by Radin.[139] According to this theory, "private property is necessary as a means of developing and realizing *one's personality*."[140] A *person's* self-identity is intertwined with their control over assets.[141] The conclusion is that every person should receive a "threshold amount of property that would enable [him or] her to function as a free individual and develop [his or] her personality."[142]

The problem is that entrusting control over protected research outputs in the hands of the researcher-inventor would deny other

134 *See id.* at 270–72. In fact, Locke specified two additional conditions, the second one being the no waste prohibition. *Id.* Since it is less relevant to the point I am trying to make here I do not discuss it further.

135 *Id.* at 259.

136 *Id.* at 259–60 (emphasis added).

137 *Id.*; *see also* Morris R. Cohen, *Property and Sovereignty*, 13 CORNELL L. REV. 8, 16 (1927) ("[E]conomic goods are never the result of any one man's unaided labor.").

138 *See* Priya, *supra* note 91, at 362–64 (discussing Hegel's personality theory as it relates to IP law). *See generally* G.F.W HEGEL, PHILOSOPHY OF RIGHT 21–272 (S.W. Dyde trans., 2001), *available at* http://socserv2.socsci.mcmaster.ca/econ/ugcm/3ll3/hegel/right.pdf (discussing throughout the entire book Hegel's philosophical theories, placing emphasis on one's mind and personality).

139 *See* Margaret Jane Radin, *Property and Personhood*, 34 STAN. L. REV. 957, 958–59 (1982).

140 Tur-Sinai, *supra* note 43, at 274 (emphasis added).

141 *Id.*

142 *Id.*

potential innovators the opportunity to develop inventions based on the protected invention and lower their chances to express their personality through such activity. From a cumulative perspective, IPRs create a conflict between the personality interest of one individual and the opportunity of other individuals to develop their own personality interest, and as a result hinders scientific progress.[143]

Furthermore, this approach, which assumes that intellectual research outputs reflect the researcher-inventor's personality regarding innovation, is less applicable with respect to technological inventions since the collaborative nature of scientific R&D results in joint research outputs, which represents the personality of each of the inventors together.[144]

Both the labor theory and the personality theory are closely tied to the romantic image of the lone inventor working in her garage by candlelight. Today, "*[t]he image of the lone genius inventing . . . from scratch is romantic . . . fiction*."[145] The innovation process no longer "*seem[s] like a sudden explosion, a crack of light above a single person*," but rather a process that involves teamwork with professionals from different disciplines and research institutions, including the private sector.[146] As discussed above, scientific R&D and innovation are becoming increasingly more collaborative.

To summarize the discussion up to this point: the patent system "is [the] primary policy tool to promote innovation, encourage the development of new technologies, and increase the [body] of human knowledge."[147] It does so by providing a "one-size-fits-all" tool,[148] in the sense that all inventions, irrespective

143 *Id.* at 281–83.

144 *See id.* at 278 (stating that in areas of technology innovation, one is much less likely to be able to express their personality, given that inventions are more the product of group work, produced by various individuals, but still an opportunity perhaps for subtle aspects of one's personality).

145 Andrew Hargadon & Robert I. Sutton, *Building an Innovation Factory*, HARV. BUS. REV. (May 2000), https://hbr.org/2000/05/building-an-innovation-factory-2 (emphasis added).

146 ORLY LOBEL, TALENT WANTS TO BE FREE: WHY WE SHOULD LEARN TO LOVE LEAK, RAIDS, AND FREE RIDING 168 (2013) (emphasis added).

147 Burk & Lemley, *supra* note 94, at 1576.

148 Dan L. Burk & Mark A. Lemley, *Is Patent Law Technology-Specific?*, 17 BERKELEY TECH. L.J. 1155, 1155 (2002); *see also* Sean B. Seymore, *Atypical Inventions*, 86 NOTRE DAME L. REV. 2057, 2058–59 (2011) (citing several scholars who criticize the one-size-fits-all attribute of the patent system).

of technological field, must satisfy the same statutory patentability criteria.[149] However, this tool applies to various technological fields, which broadly differ from one another.[150]

The patent system is concerned with identifying the individual inventive entity to which it can assign exclusive rights.[151] The underlying assumption is that innovation is an individual endeavor. Still, while this may be true with regard to certain industries, it is not the case in scientific research. The "individual inventor motif," is assumed to be the strongest in technological fields such as information technologies (IT) and business methods where independent invention is most likely to occur.[152] In these technological fields resources do not constitute high barriers to invention, and "small inventors can easily participate."[153] This is in contrast to the scientific fields in general,[154] and stem cell research in particular (as I further discuss in Part IV). The situation where an invention is developed "by one and only one" entity is becoming "exceedingly rare" in scientific R&D.[155]

Between the emphasis innovation theories put on collaboration, and the fact that scientific R&D is becoming increasingly corporate outside the patent realm, we witness a shift with regard to the identity of the inventive entity. The lone inventor, followed closely by the sole research organization, is making way for the collaboratively working inventive entities. This leads to the situation in which the premise of the patent system, its preoccupation with the individual, contradicts the

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[149] 35 U.S.C. §§ 101–03 (2012). The claimed invention must be on a patentable subject matter (§ 101), useful (§ 101), novel (§ 102) and nonobvious (§ 103). *Id.* In addition, § 112(a) requires that the application adequately describe, enable, and set forth the best mode of carrying out the invention. *Id.* § 112(a). Furthermore, § 112(b) requires that the application conclude with claims that define the invention with particularity. *Id.* § 112(a)(b).

[150] Tur-Sinai, *supra* note 43, at 251.

[151] *See* Lee, *supra* note 6, at 27 ("Thus, it is imperative for patent law to identify individual inventors to whom it can assign exclusive rights.").

[152] Cotropia*, supra* note 3, at 55.

[153] *Id.*

[154] *Id.*; *see also* John R. Allison et al., *Software Patents, Incumbents, and Entry,* 85 TEX. L. REV. 1579, 1580 (2007) (discussing the high costs of scientific innovation and stating that "the incumbents spend massive amount on research and development (R&D)—about 14% of their annual revenues, more than $60,000 per employee").

[155] Lemley, *supra* note 5, at 713.

way scientific innovation is produced.[156] It seems that the patent systems' justifications are inconsistent with how scientific R&D is currently conducted. So who gets it right? Should the lone inventor remain the focus of innovation policy, or perhaps the fact that R&D activity is conducted in collaboration should mark a shift in the way innovation is incentivized by the patent system? The next Part aims to answer these questions using the empirical methodology of patent forward citations.

IV. EMPIRICAL ANALYSIS

A. Methodology & Research Question

A patent is a legal document which grants its owner, the patentee, the right to prevent others from taking a long line of actions ("negative right"), such as buying, selling, importing, exporting, manufacturing, etc.[157] It is granted to an invention that is useful, novel and its subject matter is nonobvious.[158] A patent is also a document containing extensive information on the technology behind the invention, the inventor, the patentee, references to previous knowledge (also known as "prior art"), the inventive step, and so on.[159] Thus the patent document, which is easily accessible at a relatively low cost,[160] provides us with information on the scientific advance and economic value of the invention.[161]

When filing a patent application, the applicant must include all related prior art as references.[162] "Patent references are citations of previous relevant technology protected by or described in other patents filed anywhere in the world, at any

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156 *See* Lee, *supra* note 6, at 28 ("The communal nature of social innovation contrasts sharply with the rigid conception of individual inventorship celebrated and reified by patent law.").

157 35 U.S.C. § 154(d)(1) (Supp. 2013).

158 35 U.S.C. § 103 (2012).

159 ORG. FOR ECON. CO-OPERATION AND DEV., PATENT STATISTICS MANUAL 24, 29 (2009) [hereinafter OECD, PATENT STATISTICS MANUAL].

160 *Id.* at 13; Dirk Czarnitzki et al., *The Market Value of Blocking Patent Citations* 5 (Ctr. for Eur. Econ. Research, Discussion Paper No. 11-021, 2011), *available at* ftp://ftp.zew.de/pub/zew-docs/dp/dp11021.pdf.

161 *See* Sadao Nagaoka et al., *Patent Statistics as an Innovation Indicator*, *in* 2 HANDBOOK OF THE ECONOMICS OF INNOVATION 1083, 1085 (Bronwyn H. Hall & Nathan Rosenberg eds., 2010) (discussing the widespread development of patent databases).

162 OECD, PATENT STATISTICS MANUAL, *supra* note 159, at 24.

time, in any language."[163] "The legal purpose of the patent references is to indicate which parts of the described knowledge are claimed in the patent . . . ," and which should be excluded from the scope of protection because they have been claimed by preceding patents.[164] The grant of a patent is a legal statement that the idea it embodies makes a novel and useful contribution over and above the previous state of knowledge, as represented by the citations.[165] So in principle, a citation of Patent X by Patent Y means that X represents a piece of previously existing knowledge upon which Y is built. The citations link or pair one patent to another, thereby providing a trace of the knowledge stream, linking the production of one innovation to the earlier one.[166] This linkage includes information about the innovative value of each of the patents.[167]

Professor Manuel Trajtenberg, in his seminal work, suggests using forward citations as a proxy of the importance or value of patents.[168] He employs an econometric analysis and concludes that forward citations serve as an indicator of the innovative impact of the protected technology.[169] Put in simple words, the more citations a patent receives, the more innovative it is.

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[163] *Id.* at 107. Prior art can be both patent references and non-patent references (NPRs), which include a variety of documents, such as journal articles, conference papers, technical papers, text books, technical bulletins, technical manuals, abstracting services, database guides, standards descriptions, etc. *Id.*

[164] Paola Criscuolo et al., *Role of Home and Host Country Innovation Systems in R&D Internationalisation: A Patent Citation Analysis*, 14 ECON. OF INNOVATION & NEW TECH. 417, 422 (2005).

[165] *Id.*

[166] *See* Kenneth G. Huang & Fiona E. Murray, *Does Patent Strategy Shape the Long-Run Supply of Public Knowledge? Evidence from Human Genetics*, 52 ACAD. MGMT. J. 1193, 1201 (2009) (describing the citation system as one that builds on existing knowledge and "trace[s] the flow of ideas . . .").

[167] *See, e.g.*, Czarnitzki et al., *supra* note 160, at 11 (discussing "[t]riadic patents," the records of which have been kept since 1978).

[168] Trajtenberg, *supra* note 45, at 172–73; *see also* Bronwyn H. Hall et al., *Market Value and Patent Citation*, 36 RAND J. ECON. 1, 9 (2004) (indicating that patent citations "carry information on the value of patented innovations").

[169] *See* Trajtenberg, *supra* note 45, at 184 ("The findings . . . suggest that patent citations may be indicative of the value of innovations and, if so, that they may hold the key to unlock the wealth of information contained in patent data."); *see also* Daniele Archibugi & Mario Pianta, *Measuring Technological Change through Patents and Innovation Surveys*, 16 TECHNOVATION 451, 455 (1996) (["T]he count of citations of a patent in subsequent literature . . . is an indicator of the technological impact of the patented invention.").

The use of patent forward citations as a proxy of the innovation level of the protected technology has drawbacks. This is why their use as proxy must be done with caution. First, not all inventions are patented, such as when an organization prefers to protect the knowledge as a trade secret (for example, to gain market dominance, a practice that may differ among industries), or because the subject matter is not patentable.[170] The use of patent forward citations means that some technologies cannot be evaluated. Secondly, "[t]he value distribution of patents is . . . skewed, as a few have very high technical and economic value whereas many are ultimately never used."[171] Patent forward citations are not an indicator of the possible commercialization of a protected technology.[172] Thirdly, patent data are complex due to various factors: patent offices are diverse and their requirements vary.[173] For example, since the patent examiner is responsible for insuring that all appropriate patent citations, and other prior art, have been cited, some citations are the product of an extensive search of the state of the art conducted by examiners in order to assess the degree of novelty and inventive steps of inventions.[174] The search conducted by the European Patent Office (EPO) differs substantially from the USPTO's search.[175] This may result in differences in citation intensities. This raises concerns as to the true impact of using forward citations as a proxy.[176] Lastly, "the number of citations

[170] *See* Andrew A. Schwartz, *The Corporate Preference for Trade Secret*, 74 OHIO ST. L. J. 624, 624–25 (2013) (discussing the corporate preference between patents and trade secrets when legally protecting new inventions).

[171] OECD, PATENT STATISTICS MANUAL, *supra* note 159, at 13.

[172] *See* SIMON D. WAKEMAN, INTELLECTUAL PROPERTY PROTECTION AND TECHNOLOGY COMMERCIALIZATION STRATEGY: RECONCILING THE COMPETING EFFECTS ON LICENSING VS. FINANCING 17 (2011), *available at* http://www.oecdbookshop.org/browse.asp?pid=title-detail&lang=en&ds=&ISB=9789264056442 (stating that using patent citations "can be problematic").

[173] *See* OECD, PATENT STATISTICS MANUAL, *supra* note 159, 47–48 (discussing the national and regional differences in statutes among patent offices).

[174] *See* Jean O. Lanjouw & Mark Schankerman, *The Quality of Ideas: Measuring Innovation with Multiple Indicators* 4 (Nat'l. Bureau of Econ. Research, Working Paper No. 7345, 1999), *available at* http://www.nber.org/papers/w7345 (indicating that "[a] patent examiner skilled in the field is responsible for insuring that all appropriate patents have been cited").

[175] OECD, PATENT STATISTICS MANUAL, *supra* note 159, at 108.

[176] *See id.* at 107–08, 110 (discussing the use of forward citations to "access the technological impact of inventions," but also discussing the regional and national variations for filing patents).

received by any given patent is truncated because only the citations received [to date] are known."[177] "[P]atents of different ages are subject to differing degrees of truncation . . . [since] [t]here has been less time to cite more recent patents."[178]

With regard to patent forward citations (the number of citations a patent application receives in subsequent patent applications), two main arguments supporting their validity as indicators of the value of innovation have been presented by the OECD: "first, they indicate the existence of downstream research efforts, suggesting that money is being invested in the development of the technology", hence that there is a potential market (commercialization of the invention);[179] "second, the fact that a given patent has been cited by subsequent patent applications suggests that it has been used by patent examiners to limit the scope . . . [of the monopoly] claimed by a subsequent patentee, to the benefit of society."[180] In this sense, patent forward citations have been found to be strongly associated with the economic[181] and the social[182] value of the patented invention. In short, patent forward citations are directly related to the measurement of innovation value.[183] For this reason, forward citations are deemed the most prominent and frequently used value indicator.[184]

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[177] *Id.* at 112 (emphasis omitted).

[178] *Id.*

[179] *Id.* at 138.

[180] *Id.*

[181] *See id.* ("In this sense, forward citations indicate both the private and the social value of inventions."); *see also* Dietmar Harhoff et al., *Citation Frequency and the Value of Patented Inventions*, 81 REV. ECON. & STAT.511, 513 (1999) ("At higher citation levels, the corresponding economic value is greater . . . .").

[182] *See* Trajtenberg, *supra* note 45, at 172 ("The empirical analysis of a particular innovation . . . indeed shows a close association between citation-based patent indices and independent measures of the social value of innovations in that field.").

[183] *Id.*; *see also* Archibugi & Pianta, *supra* note 169, at 463 ("[P]atent citations, renewal fees, number of claims and number of extensions are used to account for the individual value of each patent."); Lanjouw & Schankerman, *supra* note 174, at 443 (indicating that the number of patent citations can be used to determine a patent's value); Jiancheng Guan & Ying He, *Patent-Bibliometric Analysis on the Chinese Science: Technology Linkages*, 72 SCIENTOMETRICS 403, 414–15 (2007) (discussing the use of patent citations within "science intensive" fields).

[184] *See* OECD, PATENT STATISTICS MANUAL, *supra* note 159, at 138 ("The number of forward citations is one of the most frequently used value

This article sets out to examine the question whether the patent system should continue to incentivize the individual given the increasing need for collaboration in scientific R&D. The underlying question is which R&D activity fosters more innovative technology. The methodology of patent forward citations is utilized to answer the question by comparing between the innovative strength of protected scientific R&D output conducted by the sole innovator (the focus of the patent system's incentive scheme), and another conducted collaboratively (an everyday practice in research labs and organizations).

B. The Data

1. The Case of Stem Cell Research

The stem cell industry in Israel served as the setting for testing the research question.[185] This is an appropriate setting: it is a relatively small industry, which enabled us to examine the entire population and not limit ourselves to conclusions based on a sample.[186]

Several sectors conduct stem cell research in Israel: universities, firms, medical centers and public research institutes,[187] routinely registering their stem cell research output in Israel and in countries around the world, such as the United States.[188] This article focuses on Israeli actors operating in the United States. The bottom line is that the research is corporate.[189] Unlike other research fields or industries where sole inventors can conduct research on their own, it is necessary to conduct research in research organizations due to the high

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indicators.").

185 *See* discussion *infra* Part IV.B.2.

186 *See* discussion *infra* Part IV.B.2. The population analyzed is patent families, which results in 816 patent families. This is a relatively small population.

187 *See* discussion *infra* Part IV.B.2. Public research institutes are defined here as research organizations supported by the government, but not a medical center or a university per-se. For example, a veterinarian teaching hospital supported at least partly by the government would qualify.

188 *See* NICOLA M. R. PERRIN, THE GLOBAL COMMERCIALISATION OF UK STEM CELL RESEARCH 40 (2005), *available at* http://www.chrismason.com/industry_library/assets/UKTI%20Stem%20Cell%20Res.pdf (describing Israel "'one of the leading countries' in stem cell research" and stating that "Israel has particularly strong collaborations with Australia, Singapore and the US").

189 *See supra* notes 25–26 and accompanying text.

research costs, whether for the biological materials or advanced equipment.[190]

Several critics of the methodology of patent forward citations claim that patents are not a good indicator as they are only one component of the innovation process. However, an important trait of stem cell research is that no products are currently being marketed to customers and some uncertainty still remains regarding the viability of research outputs.[191] The most advanced studies in this field are only at the clinical trial stage.[192] In this case patents constitute a good indicator since the innovation process does not end with the diffusion of a product into the market[193] but with the generation of inventions. Concomitantly, since intellectual property protection plays a relevant role in the stem cell industry in Israel,[194] patents function as appropriate proxies to capture the value of innovations.[195]

2. Data Collection

The data included 816 patent families whose inventor and/or assignee is based in Israel and for which a patent application or a registered patent was filed in the United States.[196] A patent family is a group of patents, which, like the members of a family, are all related by way of the priority of a particular patent document, *i.e.*, the first patent application.[197] The families

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[190] *See supra* notes 25–26 and accompanying text.

[191] *See Adult Stem Cell Research Shows Promise,* CONSUMER HEALTH INFO., (U.S. FOOD & DRUG ADMIN.), Apr. 2014, at 2, *available at* http://www.fda.gov/downloads/ForConsumers/ConsumerUpdates/UCM394489.pdf ("[S]tem-cell based clinical trials have not yet resulted in a marketed product."). Apart from cosmetics products whose effectiveness has not yet been determined, and in any event are not included in the scope of this paper.

[192] *Id.*

[193] BENGT-ÅKE LUNDVALL, INTRODUCTION TO CENTRAL CONCEPTS IN INNOVATION MANAGEMENT AND INNOVATION RESEARCH 1 (2007), *available at* http://www.globelicsacademy.net/2011_pdf/Lundvall%20-%20Introduction%20on%20Innovation.pdf.

[194] ELKIN-KOREN ET AL., *supra* note 87.

[195] For example, scientists from public research institutions in the stem cell field in Israel are cited stating that firms do not establish collaboration with a prospective partner without being certain that its knowledge is well protected. Patents provide just that, even though they are not the only mechanism available, and the use of trade secret to protect invention in the stem cell field is scarce. *See id.*

[196] *See infra* Table 1.

[197] *See* Onder Nomaler & Bart Verspagen, *Knowledge Flows, Patent Citations*

include both registered patents and patent applications, as the two could not be separated in the database used. Aggregating the data into families overcomes the problem of equivalents. Citations for a patent can vary. A given invention can be covered by a number of documents issued by different offices.[198] A group of patent equivalents make up a patent family.[199] This may lead to underestimation of citation counts because each equivalent is cited by a different patent, that is, the citations of a given invention are spread across the different versions of a patent family, with the result that these different citations may not being taken into account in the analysis.[200]

The data were collected by first mapping the actors in this field of research in Israel. A list of all Israeli research organizations and scientists was created. A search was then conducted using PatBase.[201] The list was uploaded to PatBase as assignees. The search was circumscribed to the key words "stem cell(s)" in the title, abstract, and claims of the patents in the database. Some Israeli research organizations emerged that were missing from our initial mapping. If such an organization was indeed active in stem cell research in Israel, it was added to the list and a further search for its stem cell related patents was conducted. The key-words search was then repeated, now limited to the relevant classes. When the search discovered research organizations missing from the initial mapping, they were further investigated and a patent search was conducted.

The search produced 1,047 patent families. Rigorous and manual data cleanup was required. Since this study focused on sectors, over 3,000 institutional assignees had to be identified. However, due to the definition of collaboration employed in this article, almost 4,000 inventors and their institutional affiliation

and the Impact of Science on Technology, 20 ECON. SYS. RES. 339, 345 (2008) (defining the term patent family as "a set of patents filed under different patent systems (e.g., EPO, USPTO), but covering the same invention").

[198] *See, e.g.*, Dietmar Harhoff et al., *Citations, Family Size, Opposition and the Value of Patent Rights*, 1596 RES. POL'Y 1, 3 (2005) (discussing patents of German applicants, some of which were opposed or not renewed to a full term).

[199] *Id.*

[200] *See* OECD, PATENT STATISTICS MANUAL, *supra* note 159, at 111 ("[C]ounts of citations are underestimated because citations of a given invention are spread across the different versions of a patent family.").

[201] *See generally* MINESOFT & RWS GROUP, INTRODUCTION TO PATBASE (2003), *available at* https://www.patbase.com/pboverview.pdf (providing further explanation of PatBase).

had to be identified as well.[202] Each of the (affiliated) inventors, institutional assignees and private assignees[203] was assigned to one of the four sectors operating in the stem cell field. The identification process was far from perfect due to the need to identify foreign assignees as well.[204] Identification was accomplished by means of LexisNexis Academic[205] to retrieve information about companies, and by an Internet search for information not available via Lexis. This search was not free of errors.

Another problem encountered in identifying the assignees was incomplete information or numerous spelling mistakes in the patent document. For this reason, the names of inventors and assignees had to be normalized, manually correcting the names during the identification process to ensure that a patent was assigned to its rightful owner and inventors. To ensure that the analysis adhered to the definition of collaboration employed in this article, patents owned by an international institution, but, for example, whose inventors belonged to an Israeli university, were carefully scrutinized. In this manner, a patent that represented a licensed or acquired technology was removed from the data. Furthermore, when additional research revealed, with regard to co-assignments by two firms, that at some time one firm bought the other, the patent was deemed solely owned or collaborative according to the transaction date. If the transaction date was prior to publication date, the patent was deemed collaborative. But if the transaction date was later then the publication date, the patent was deemed solely owned. This process was of course not error-free and great effort was invested to ensure that collaborative patents in the data concurred with the definition of collaboration. Following this process we were left with 1,016 patent families

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[202] *See generally* Nagaoka et al., *supra* note 161; *see also* Sébastien Lechevalier et al., *Investigating Collaborative R&D Using Patent Data: The Case Study of Robot Technology in Japan*, 32 MANAGERIAL & DECISION ECON. 305 (2011) (offering a discussion of similar methodologies).

[203] A small number of the patentees are inventors who appear in the patent/application documentation as the patentee as well, an honor usually saved for "star scientists."

[204] *See* OECD, PATENT STATISTICS MANUAL, *supra* note 159, at 97–98 (providing more information on the general difficulties of the cleanup process).

[205] *See* LEXISNEXIS ACADEMIC, http://www.lexisnexis.com/en-us/products/lexis nexis-academic.page (last visited Apr. 15, 2015) (offering further background regarding the LexisNexis Academic research database).

In the final stage it was necessary to identify which of the 1,016 patent families included a patent application or a registered patent that was filed with the USPTO.[206] At the end of this process the data contained 816 patent families.

For every patent family in the data, information was also collected on its "age," the "birth date" defined as the date it was first published (known as earliest publication date). The patent families were first published between January 1977 and March 2013. Further information was gathered on the number of cited patents of each family. For convenience, and unless otherwise mentioned, I use the term "patents" as an overall name for both registered patents and patent applications, and instead of the term "patent families." The information gathered is updated for the period up to June 2013.

The data are classified into two categories: non-collaborative patents and collaborative patents, referred to as *patent type*. Collaborative patents are classified into two sub-categories: patents representing intra-sector collaborations (*e.g.,* university-university) and those representing inter-sector collaborations (*e.g.*, university-firm). Table 1 shows the number of patents assigned to each group and their percentage in the data.

Total number of patents	Non-collaborative	Collaborative patents	
		Intra-sector collaborations	*Inter-sector collaborations*
816	565	56	194
100%	69%	7%	24%

Table 1: Summary of number and percentage of patents by patent type

Out of 816 patents, 69 percent or 565 are non-collaborative, they are owned by one research organization; 194 patents or 24 percent of the data represent inter-sector collaboration. A small number of patents, 56, which make up only 7 percent of the data, represent intra-sector collaborations.

[206] *See Search for Patents*, U.S. PAT. & TRADEMARK OFF., http://www.uspto.gov/patents-application-process/search-patents (last visited Apr. 15, 2015) (providing several online resources for browsing patents applications).

V. RESULTS & DISCUSSION

To examine the research question I employed the Weighted Least Squares Regression using the data analysis and statistical software Stata 12.1.[207]

Table 2 summarizes the measures used and the control variables:

Independent Variables	
no_collab	Dummy variable, represents patents resulting from R&D conducted by one research institution. Due to the "dummy variable trap"[208] the non-collaborative patents are represented by the constant (_cons) (which is also the intercept β_0). The coefficients of the following variables should be read in comparison with the constant coefficient, as it serves as a "base line."
intra_collab	Dummy variable, represents patents resulting from joint R&D activity between research institutions from different sector types.
inter_collab	Dummy variable, represents patents resulting from joint R&D activity between research institutes from the same sector type.

[207] *See* William W. Gould & Nicholas J. Cox, *History of Stata*, STATA.COM (2015), http://www.stata.com/support/faqs/resources/history-of-stata/ (listing the current version of Stata and its earlier releases, including version 12.1).

[208] In regression analysis, we should always include in the model one less dummy variable than there are categories, otherwise we introduce multicollinearity into the model. The dummy variable trap occurs in the case of perfect multicollinearity. If we include all dummy variables, they exhaust the set of possible categories, so the sum of these dummy variables is always 1 for each observation in the regression data set. The presence of a constant which receives the value of 1 no matter which dummy variable is spotted in the observation, leads to multicollinearity between the constant and dummy variables for each observation. To solve this we need to drop one of the dummy variables. The sum of variables will then no longer equal one for every observation in the data. In our case Stata omitted the *no_collab* variable. It does not matter which one you drop, and Stata does this automatically. However, changing the "default" category does change the coefficients since, as discussed below, all dummy variables are measured relative to this "default" reference category. The remaining dummy variables effects are measured relative to the missing dummy variable, which effectively is now picked up by the constant term.

Collab	Dummy variable, represents collaborative patents in general. Includes both inter-sector and intra-sector types of patents.
Dependent Variables	
Numfct	Number of forward citation each of the patent family received.
Control Variables[209]	
age_year	The age of the patent family in years, calculated from first publication.
citation_lag	The time elapsed in years since first publication of the patent family until first cited (by citing patent's first publication date).

Table 2: Measures and controls

Table 3 summarizes the descriptive statistics of the variables:

Variable	Obs	Mean	Std. Dev.	Min	Max
no_collab	816	.692402	.4617822	0	1
intra_collab	816	.0686275	.2529746	0	1
inter_collab	816	.2389706	.4267163	0	1
collab	816	.307598	.4617822	0	1
numfct	816	15.41912	33.82018	0	453
age_years	816	10.3174	6.341101	0	36
citation_lag	668	2.791916	1.99026	0	13

Table 3: Descriptive statistics

The method of Weighted Least Squares Regression assumes the following linear relationship between the variables (see Appendix A for more detailed explanation).

Equation1: $$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \ldots + \beta_k x_{ki} + u_i$$

y_i represents the estimated values of forward citations. The other side of the equation shows the explanatory variables. Table 4 presents the results of the hypotheses testing.

Collaborative patents generate an expected mean of 3 forward citations more than non-collaborative patents (specification (1)).

[209] *See infra* Appendix A (providing information on why these controls were included in the model).

The age of the patent has an influence as well. We see that each year adds 2 additional forward citations to the patent.

When we divide the collaborative patents into patents representing inter-sector collaborations and those representing intra-sector collaborations, we see that inter-sector collaborations generates an expected mean of 4 forward citations and intra-sector collaborations generate an expected mean of 1 forward citation, more than non-collaborative patents (specification (2)).

Due to the small number of patents representing intra-sector collaborations, the analysis will focus on patents representing inter-sector collaborations. We can see that in specification (3) the coefficient of the variable *collab* is not statistically significant. A possible reason for this is that *collab* also includes data on patents representing intra-sector collaborations. The small number of observations (7 percent) disrupts the analysis.

Specifications (4)–(5) include more variables as we move to the complete model, represented in specification (6). Specification (4) includes the interaction variable *life_span*, which is the result of the following interaction: $inter\_collab \times age\_years$. By doing so we set out to examine the forward citations patterns throughout the life span of inter-sector collaboration type patents. This is not the same as the age of the patents, as we already control for age in the model. In specification (5) we added the control variable *citation_lag*, which leads us to the complete model in specification (6). Specification (6) also includes the interaction variable *enter_market*. This variable is the result of the interaction between the following variables: $inter\_collab \times citation\_lag$. It represents how quickly the inter-sector collaboration type of patent entered the "citation market."

Equation 2 presents the model of specification (6). We can estimate the expected mean of forward citation for every year of the inter-sector collaboration type of patent and for every lag.

Equation 2:
$$\hat{y}_i = -7 + 3.5 \times inter\_collab + 2 \times age\_years + 0.1 \times span + 0.4 \times citation\_lag - 1.5 \times enter\_market$$

Equation 3 shows the delta (Δ) of forward citations added by the type of collaboration, inter-sector collaborations, to the total sum of forward citations on the basis of specification (6), as we are interested in the relationship between innovation and collaboration.

Equation 3: $$\Delta inter\_collab = 3.5 + 0.1 \times span - 1.5 \times enter\_market$$

	(1) numfct	(2) numfct	(3) numfct	(4) numfct	(5) numfct	(6) numfct
collab	2.844***		-1.782			
	(6.93)		(-0.75)			
age_years	1.701***	1.697***	1.410***	2.312***	2.104***	1.821***
	(8.14)	(7.46)	(5.42)	(11.48)	(6.56)	(5.50)
inter_collab		4.183***		6.522**	5.844**	3.503
		(8.79)		(2.46)	(2.14)	(1.24)
intra_collab		1.338**				
		(2.42)				
collab_age			0.932**			
			(1.99)			
life_span [=inter_collab x age_years]				-1.222**	-1.091**	0.117
				(-2.51)	(-2.19)	(0.18)
citation_lag					0.160	0.379**
					(0.84)	(1.97)
enter_market [=inter_collab x citation_lag]						-1.518***
						(-2.75)
_cons	-5.928***	-5.926***	-4.484***	-8.459***	-7.739***	-6.759***
	(-5.60)	(-5.15)	(-3.42)	(-8.63)	(-5.88)	(-5.07)
N	816	816	816	668	668	668
R-sq	0.127	0.146	0.131	0.178	0.188	0.254

t statistics in parentheses
* p<0.1, ** p<0.05, *** p<0.01

Table 4: Regression results

Table 5 below summarizes the effect of inter-sector collaborations on the total expected mean of a patent's forward citations, by examining the influence of the change of the patent's age (from 10 years to 15 years) and of the change in citation lag (from 2 years to 1 year). These values are placed in Equation 3 as the interaction variables refer to age and citation lag respectively.

age = 10 citation lag = 2	$\Delta \boldsymbol{inter\_collab} = \mathbf{3.5 + 0.1 \times 10 - 1.5 \times 2 = 1.5}$
age = 15 citation lag = 2	$\Delta \boldsymbol{inter\_collab} = \mathbf{3.5 + 0.1 \times 15 - 1.5 \times 2 = 2}$
age = 15 citation lag = 1	$\Delta \boldsymbol{inter\_collab} = \mathbf{3.5 + 0.1 \times 15 - 1.5 \times 1 = 2.5}$

Table 5: Example of the effect of inter-actor collaboration (delta) on the total expected mean of forward citations

The visible trend revealed in the results presented in Table 5 is that the number of citations added by the collaboration increases as the collaborative research output matures over time, and increases as the time it takes the collaborative research output to be cited shortens.

VI. SUMMARY & RAMIFICATIONS

This article sets out to examine whether the patent system should continue incentivizing innovation produced by an individual given the increasing need for collaboration in scientific R&D.

This article began by presenting the framework of the research question. Classical reasoning and justifications which maintain that the patent system fosters innovation through inventions is biased in the sense that it favors and places great emphasis on the individual. At the beginning this "individual" was truly a lone inventor working in her garage.[210] However, as science became corporate the concept evolved to include the sole research organization. Scientific R&D has evolved even further.

[210] Cotropia, *supra* note 3, at 54.

Collaboration has become a much needed practice due to the growing complexity of scientific R&D which requires more specialized knowledge, more than any single individual or research organization can be expected to possess.[211] Through collaboration access is granted to additional expertise and knowledge that in turn assists in mitigating the complexity of scientific R&D.

An empirical analysis is then provided to answer the research question. Using the methodology of patent forward citations the analysis shows that with regard to Israeli actors in the stem cell field which apply for protection in the United States, collaborative R&D generates more forward citations than non-collaborative endeavors conducted by the individual research organization. It also reveals that patents representing both intra-sector and inter-sector collaborations have a higher expected mean of forward citations compared to non-collaborative patents.

Further analysis which focused on inter-sector collaborative type patents (due to the small number of patents representing intra-sector collaborations, which led to statistically insignificant coefficients) showed that inter-sector collaborations produce more groundbreaking knowledge. Moreover, inter-sector collaborative type patents are cited more as they mature, meaning that over their life span the knowledge they offer is utilized to a greater extent in order to establish a new layer of knowledge (in contrast to non-collaborative type patents). Also, and in a sense the other side of the same coin, inter-sector collaborative type patents enter the market of citations quicker than non-collaborative type patents. This is demonstrated by the influence citation lag has on these patents. The shorter the citation lag the more they are cited. These results strengthen the initial conclusion that, with regard to Israeli actors operating in the United States stem cell market by filing patent applications, collaborations generate more innovative technology compared to non-collaborative R&D activity.

[211] *See* Lee & Bozeman, *supra* note 77, at 673 ("The increasingly interdisciplinary, complex, and costly characteristics of modern science encourage scientists to get involved in collaborative research."); *see also* Hara et al., *supra* note 58, at 953 ("Collaboration is often a critical component of research in the world of big science."); Galison, *supra* note 76, at 2 (stating that the "rapid growth of big science" has resulted in the loss of "individual autonomy"); Bubela et al., *supra* note 21, at 26 (discussing "[c]ollaboration networks").

Stem cell research was not chosen as an exemplary case offhand. Apart from its small size, which enables us to examine the entire industry without requiring the use of a sample, it represents the way modern scientific research is conducted and provides the appropriate setting to examine the research question.

The philosopher and scientist Michael Polanyi stated that acquiring and discovering knowledge are both deeply collective and deeply individual endeavors.[212] He was right in the sense that the creativity of individual scientists spins the wheels of the research organization. Having said that, policymakers should place far more emphasis on the ever-growing practice of scientific collaboration, as collaborations generate innovative and groundbreaking technology, and innovation is the engine that propels the economy forward.

From a policy perspective, policymakers should address the conflict between how innovation is captured by the patent system—the patent system relies upon and reinforces a somewhat distorted conception of the innovative process as an individual endeavor—and how innovation is produced in the world of scientific R&D—collaboratively. Policymakers should recognize and account for the patent system's narrow perspective of innovation, and address the gap between this limited view and the collaborative nature of scientific innovations, otherwise invention and innovation are at risk due to insufficient incentives.

While this article discusses only one field of scientific research, albeit a field that realistically represents how scientific R&D is conducted, other fields should also be examined. The methodology presented here can be applied to other fields as well. The aim of this article was not to provide solutions, which should be addressed separately, but to shed light on the incompatibility between the patent system's perception of innovation production and the way it is in fact produced in real-life.

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[212] *See generally* MICHAEL POLANYI, PERSONAL KNOWLEDGE: TOWARDS A POST-CRITICAL PHILOSOPHY (1962) (theorizing that knowledge is personal but also collective).

APPENDIX A: STATISTICAL INFORMATION

1. Weighted Least Squares Regression

Breusch-Pagan/Cook-Weisberg tests the null hypothesis (H_0) that the error variances are all equal versus the alternative that the error variances are a multiplicative function of one or more variables. The alternative hypothesis (H_1) states that error variances increase (or decrease) as the predicted values of Y increase, *i.e.*, the higher the predicted value of Y, the bigger the error variance. Thus if the p-value is very small, we would have to reject the hypothesis and accept the alternative hypothesis that the variance is not homogenous. In Figure 1 p-value is zero, which indicates that heteroscedasticity is present.[213]

```
Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of sum_numfct

         chi2(1)      =   750.96
         Prob > chi2  =   0.0000
```

Figure 1: Breusch-Pagan/Cook-Weisberg test

To overcome the presence of heteroscedasticity, I used Weighted Least Squares Regression.[214] I assumed that the variance depends on age for specifications (2)-(4) because of the "truncation effect" (see below). In specifications (5)-(6) I assumed that the variance depends on citation lag as well, due to different citation practices. I used Weighted Least Squares Regression in order to use the best linear unbiased estimator (BLUE).

2. Age

Age is entered as a control variable because of a phenomenon known as "right-truncation." Older patents are cited more

[213] *See* STATA WEB BOOKS, REGRESSION WITH STATA, CHAPTER 2 - REGRESSION DIAGNOSTICS 14 (2005), *available at* http://www.ats.ucla.edu/stat/stata/webbooks/reg/chapter2/statareg2.htm (discussing heteroscedasticity and homoscedascticity).

[214] *See Stata Analysis Tools: Weighted Least Squares Regression,* UCLA INST. DIGITAL RES. & EDUC., http://www.ats.ucla.edu/stat/stata/ado/analysis/wls0.htm (last visited Apr. 15, 2015) ("Weighted least squares provides one method for dealing with heteroscedasticity.").

frequently than recent patents because the pool of potentially (future) citing patents is smaller.[215] This means that for patents first published in 2013, the date the data were constructed, we only have information on their prior art, as cited in the application, but we do not know into which future patents they will be incorporated (as prior art).[216] Table 6 below shows a strong positive correlation between age and number of forward citations of a given patent. Figure 2 provides more information by showing that the relationship between these two variables is linear, thus asserting the existence of the truncation effect. For this reason I added age into the model as a control variable.

	age_years	avg_NUMFCT
age_years	1.0000	
avg_NUMFCT	0.7995	1.0000

(obs=816)

Table 4: Correlation matrix between age (in years) and the number of forward citations (average)

[215] *See* E. Bacchiocchi & F. Montobbio, *Knowledge Diffusion from University and Public*
Research: A Comparison Between US, Japan and Europe Using Patent Citations, 34 J. TECH. TRANSF. 169, 175 (2009) ("[R]ecent cohorts of patents are less likely to be cited then the older ones, because the pool of potentially citing patents is smaller.").

[216] Nomaler & Verspagen, *supra* note 197, at 343.

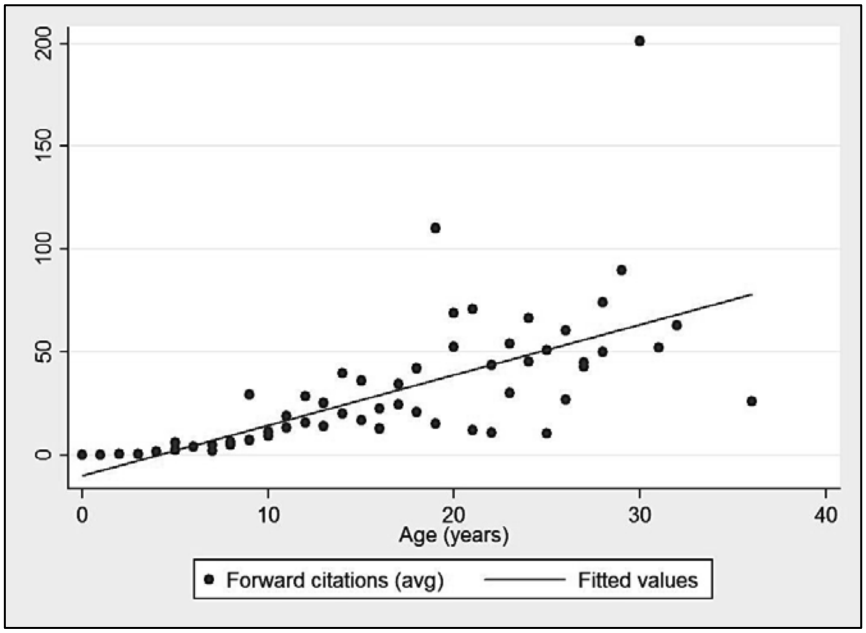

Figure 2: The linear connection between forward citations (average) and age (in years)

3. Citation lag

If we place the coefficients in specification (2) (Equation 4) we can estimate the expected mean of forward citations for each patent type and according to the age of the patent.

Equation3: $\hat{y}_i = -6 + 2 * inter\_collab\ + 4 * intra\_collab + 1 * age\_years$

Citation lag was entered into the model as a control variable since when the value of age was introduced to the model we have noticed that for inter-sector collaboration type patents the age of the patent should be at least 5 to obtain a positive value of forward citations (Equation 5). For intra-sector collaboration type patents the value of age needed to be at least 3 (Equation 6).

Equation 4: $\hat{y}_{inter\_collab} = -6 + 2 * 1 + 4 * 0 + 1 * \mathbf{5} = 1$

Equation 5: $\hat{y}_{intra\_collab} = -6 + 2 * 0 + 4 * 1 + 1 * \mathbf{3} = 1$

For the non-collaborative patents, however, in order to obtain a positive value of forward citations the age has to be at least 7 years (Equation 7).

Equation 6: $\hat{y}_{no\_collab} = -6 + 1 * 0 + 4 * 0 + 1 * \mathbf{7} = 1$

In sum, when age is introduced as a control variable into specification (2), non-collaborative patents take longer to be cited by future patents than collaborative patents.

4. *F*-test

The interaction variable *life_span* is not statistically significant (specification (6)), it does not necessarily mean that the coefficient cannot be taken into consideration during the estimation process. We can use an *F*-test to examine whether a group of variables has no effect on the dependent variable. More precisely, the null hypothesis is: a set of variables has no effect on *y*, once another set of variables has been controlled ($H_0: \beta_1 = 0,\ \beta_2 = 0,\ \beta_k = 0$).[217] With regard to specification (6) we examine the following group of variables: *inter_collab*, *life_span* and *enter_market*, while controlling the variables *citation_lag* and *age_years*.

F-test is conducted following a specific regression. Here the regression embodies specification (6) (Table 7). The *F*-test of the variables *inter_collab*, *life_span* and *enter_market* is statistically significant (Figure 3), thus null hypothesis is rejected.

[217] *See generally* Jeff Hamrick, *The Restricted F Test for Multiple Linear Regression in Stata*, YOUTUBE (Feb. 6, 2013), https://www.youtube.com/watch?v=pepVZHloM4E (providing a brief discussion regarding the proper implementation of a partial F test).

WLS regression - type: proportional to e^2
(sum of wgt is 1.0898e-01)

Source	SS	df	MS		
Model	2353.06773	5	470.613546	Number of obs =	668
Residual	6902.27549	662	10.426398	F(5, 662) =	45.14
				Prob > F =	0.0000
				R-squared =	0.2542
Total	9255.34322	667	13.8760768	Adj R-squared =	0.2486
				Root MSE =	3.229

sum_numfct	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
inter_collab	3.503088	2.819835	1.24	0.215	-2.03381	9.039985
age_years	1.821316	.3314171	5.50	0.000	1.17056	2.472071
life_span	.1167274	.6512706	0.18	0.858	-1.162077	1.395532
citation_lag	.379275	.1924494	1.97	0.049	.0013902	.7571598
enter_market	-1.518188	.5513498	-2.75	0.006	-2.600793	-.4355826
_cons	-6.759168	1.333319	-5.07	0.000	-9.377211	-4.141125

Table 7: Regression results of specification (6)

```
. test inter_collab life_span enter_market

 ( 1)  inter_collab = 0
 ( 2)  life_span = 0
 ( 3)  enter_market = 0

       F(  3,   662) =    4.01
            Prob > F =    0.0076
```

Figure 3: *F* test of variables *inter_collab*, *life_span* and *enter_market*