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Exclusive Rights Stimulate Design-Around: How Circumventing Edison's Lamp Patent Promoted Competition and New Technology Development

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ABSTRACT

Designing around patents is prevalent but not often appreciated as a means by which patents promote economic development through competition. We provide a novel detailed empirical study of the extent and timing of designing around patent claims. We study the filing rate of incandescent lamp-related patents during 1878-1898 and find that the enforcement of Edison's incandescent lamp patent in 1891-1894 stimulated a surge of patenting. We studied the specific design features of the lamps described in these lamp patents and compared them to Edison's claimed invention to create a count of non-infringing designs by filing date. Most of these non-infringing designs circumvented Edison's patent claims by creating *substitute* technologies to enable participation in the market. Our forward citation analysis of these patents show that some had introduced pioneering prior art for new fields. This indicates that invention around patents is not duplicative research and contributes to dynamic economic efficiency. We show that the Edison lamp patent did not suppress advance in electric lighting and the market power of the Edison patent-owner, *weakened* during this patent's enforcement. We propose that investigation of the effects of design-around patents is essential for establishing the degree of market power conferred by patents.

Keywords: incandescent lamp; invent around; licensing; infringement; monopoly, General Electric.

JEL Codes: D21, D22, K11, K21, L11, L12, N61, O31, O32, O33, O34.

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1 Introduction

We propose that "design around" patent claims is a widely-practiced but underestimated feature of the patent system. Design around patent claims promotes competition that often limits the practical scope of market control that patentees obtain through their exclusive patent rights. As such, design-around should be regarded as a social welfare-enhancing pro-competitive practice to be added to the list of cogent reasons why the economic harms sometimes conjectured to result from exercise of exclusive patent rights are not realized in practice.[3]

The conjectured harm that design around does much to limit has been called the "persistent error" in the economic analysis of patents, the modelling of patents *as if they are* economic monopolies so that the generally-accepted adverse outcomes of economic monopoly are presumptively attached to the analysis of exclusive patent rights in general.[4] In contrast, we argue that if a patented invention does create a large economic surplus ostensibly protected by economic monopoly, it should also be assumed that intensive *efforts* will be made to design around the patent's claims. Whether those efforts are successful in preventing the exercise of market power is an empirical matter, as in the Edison case. The danger of *not* assessing design around effects is also well illustrated in the Edison case — the erroneous assumption that the patent had conferred an economic monopoly goes unchallenged, an error that we find in sources on Edison's incandescent lamp patent.[5]

If design-around is a commercially-feasible strategy, then it follows that it provides a practical check on both a patentee's ability to exclude others from the advance and the patentee's ability to charge "excessive royalties;" the higher the royalty the greater the economic incentive to design a substitute technology. The possibility of design-around should also be a practical check on the patentee's ability to exercise monopoly pricing; indeed the Edison case shows that a

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[3] *See* Daniel F. Spulber, *How Patents Provide the Foundation of the Market for Inventions,* 11 JOURNAL OF COMPETITION LAW & ECONOMICS 271 (2015) (Shows how contrary to conjectures of economic harms, patents underpin the market in inventions by increasing transaction efficiency, stimulating competition and promoting the financing of innovation); Alexander Galetovic, et al., *An Empirical Examination of Patent Holdup*, 11 JOURNAL OF COMPETITION LAW & ECONOMICS (2015) (Showing contrary to the "patent holdup" conjecture, that patent-intensive industries have the fastest quality-adjusted price declines in the U.S.); J. Gregory Sidak, *Is Patent Holdup a Hoax?*, 3 THE CRITERION JOURNAL ON INNOVATION 401, 410-411 (2018) (Reviewing the inadequate response of the proposers of the patent holdup conjecture to the extensive body of empirical and modelling work contradicting the conjecture's testable predictions); David J. Teece, *The "Tragedy of the Anticommons" Fallacy: A Law and Economics Analysis of Patent Thickets and FRAND Licensing,* 32 BERKELEY TECH. L.J. 1489 (2015) (Explaining contrary to the "anticommons" conjecture through empirical examples how institutional adaptations have the result that predicted underuse of patented technology does not occur); Adam Mossoff, *The Rise and Fall of the First American Patent Thicket; The Sewing Machine War of the 1850s,* 53 ARIZ. L. REV., 165 (2011) (Finding contrary to the conjecture holding public intervention to limit patent rights as necessary in patent-intensive industries, that putative licensing problems were resolved through the private organization of the first U.S. patent pool); Jonathan M. Barnett, *Has the Academy Led Patent Law Astray?* 32 BERKELEY TECH. L.J. 1313 (2018) (Finding that the empirical evidence contradicts scholarly conjectures that technology markets fail, noting that policy makers have weakened injunctive relief in response to the conjectures and warning that this "depropertization" will discourage innovation); Geoffrey A Manne and Joshua D Wright, *Innovation and the Limits of Antitrust,* 6 JOURNAL OF COMPETITION LAW AND ECONOMICS 153 (2010) (Noting that while economists and courts have had the hostile assumption that the novel business practices produced by the exploitation of exclusivity are the result of economic monopoly, but that a more nuanced understanding of the pro-competitive virtues of novel practices typically develops with time and may filter into the antitrust field). These results are not appreciably different when enforcement is by "non-practicing" patent holders: *See, e.g.* Michael Risch, *Patent Troll Myths,* 42 SETON HALL L. REV., 457 (2012) (Presenting empirical analyses that show an absence of the alleged harm done by patent enforcement by non-practicing patent owners and further that this enforcement is indistinguishable from enforcement by patent-owning developers); Jay Kesan et. al., *Understanding Patent "Privateering": A Quantitative Assessment* 16 J. EMPIRICAL LEGAL STUDIES 343 (2019) (same).

[4] See Edmund W. Kitch, *Elementary and Persistent Errors in the Economic Analysis of Intellectual Property*, 53 VANDERBILT LAW REVIEW 1727, 1729-1738 (2000) (Arguing that the availability of substitutes; the time taken to develop an important broad scope invention to market; the narrow claims of a patent in a highly-developed field and the short term of the patent all weigh against this being the typical case for patents).

[5] *See* ARTHUR A. BRIGHT, THE ELECTRIC-LAMP INDUSTRY: TECHNOLOGICAL CHANGE AND ECONOMIC DEVELOPMENT FROM 1800 TO 1947, 89-90 (Macmillan Co., 1949) (Describing the GE's enforcement of Edison's lamp patent as "attempting to put all competitors out of the lamp business and secure a complete monopoly. *For twelve years competition had been possible; it suddenly became impossible*… … A few other companies *remained in production or reopened their plants by redesigning their lamps*… In addition, many new companies were formed after 1892 to produce *"non-infringing" lamps*. From 1892 till the expiration of the patent, there were probably ten or more competing producers making lamps at all times, despite the vigorous efforts of [GE] to close them down" (our emphasis). The italicised text "For twelve years competition… became impossible" is quoted in Robert P. Merges and Richard R Nelson, *On the Complex Economics of Patent Scope,* 90 COLUMBIA LAW REVIEW 839, 885 (1990).

patent, even when aggressively enforced, may cause intense price competition and fail to confer "market" power," let alone "monopoly power," on its owner.

It should therefore be recognized that a patent is not an economic monopoly —a patent only confers a time-limited exclusive right to a *new* invention. And "[a] time-limited exclusive right to subject matter which was neither known, nor obvious from what was known, takes nothing from the public which it had before."[6] Nevertheless, patents teach the world *more than their legal claims can capture for exclusive control,* and design-around those legal claims may involve invention of new technology and is often more than mere "imitation." When such advancement produces *patented* inventions, we may use the term "inventing around"; but in general a design-around may not be an invention-around because it does not *require* invention and patenting — sometimes a particular use of prior art may suffice to achieve its object. When it occurs, as in the Edison case, invention-arounds that introduce important new technology and pioneering contributions to downstream development can foster dynamic economic efficiency.

A patent comprises two separate components: the *description* and the *claims*. The former includes a written description of the invention and of the manner and process of making and using it. Where the nature of the subject matter admits of illustration, the description also contains one or more drawings. A patent also contains claims particularly pointing out and distinctly claiming the invention. The claims in a patent are the legal description of the technology subject to the exclusive patent right. The claims are like the descriptions of lands by metes and bounds in a deed which define the area conveyed. The defined boundaries are intended to afford clear notice of the claimed invention, thereby apprising the public of what is still open to them. Unlicensed market participants who wish to sell a competing product during the term of the patent must avoid the scope of the patent's claims in order to avoid infringement liability. When it is technically and commercially feasible, the ability to "design around" patent claims protects such providers and permits them participation in the technology field. Development of their design-arounds may also advance technology in novel directions other than that of the pioneer patent and its improvements.

The object of design-around is often a technological *substitute,* and so possibly a commercial substitute, for the target patented invention. Such substitutes that involve invention-around could be considered part of what the literature calls "cumulative" invention in which inventive efforts are directed at – for example – improving and "building upon" existing patented technology.[7] However, because inventions-around fall outside the scope of the target patent claims and are therefore not subject to the patent holder's exclusivity, they are outside the class of cumulative (infringing) improvements that concerned Scotchmer's 1991 policy paper. In principle, in the development of a significant field, there is reason to expect both types of cumulative invention to occur – the pioneer patent holder and its licensees (if any) have strong incentives to improve the basic invention, and those inventing-around the pioneer patent claims have incentives to produce technologically and commercially viable *non-infringing* substitutes that require no license from the pioneer patent holder.

Designing around patents is not an esoteric or narrowly specialized activity—it is prevalent. As early as 1960, a majority (57%) of professional managers of innovation development consider competitors' patent claims and manage designs around them as a staple of their practice.[8] And as we show below, the literature captures these professionals' awareness of the importance and benefits of designing around patent claims, as have government institutions. The U.S. Supreme Court recognized the difference between "the intentional copyist making minor changes to lower the risk of legal action" and "the incremental innovator designing around the claims, yet seeking to capture as much as is permissible of the patented advance"[9]; the U.S. Court of Appeal for the Federal Circuit observed that "[d]esigning around patents is, in fact, one of the ways in which the patent system works to the advantage of the public in promoting progress in the useful arts, its constitutional purpose."[10] Evidence on the ease or difficulty of designing around a patent claim is a factor often used by the courts in analyzing hypothetical licensing negotiations to determine infringement

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[6] Judge Giles S. Rich, *Laying the Ghost of the 'Invention' Requirement,* reprinted in 41 AIPLA Q. J. 1, 5-6 (2012). In contrast, monopoly power is "a high degree of market power," which is defined as "the ability of a firm (or a group of firms, acting jointly) to raise price above the competitive level without losing so many sales so rapidly that the price increase is unprofitable and must be rescinded." William M. Landes & Richard A. Posner, *Market Power in Antitrust Cases*, 94 HARV. L. REV. 937, 937 (1981).

[7] Suzanne Scotchmer, *Standing on the Shoulders of Giants: Cumulative Research and the Patent Law*.' 5 JOURNAL OF ECONOMIC PERSPECTIVES 29 (1991).

[8] Russell M. Otis and William D. Sellers, *Our Patent System Works: A Reply to the Melman Report*, 42 JOURNAL OF THE PATENT OFFICE SOCIETY 295 (1960)

[9] *Warner-Jenkinson Co. v. Hilton Davis Chem. Co.*, 520 U.S. 17, 36 (1997).

[10] *Slimfold Mfg. Co. v. Kinkead Indus.*, 932 F.2d 1453, 1457 (Fed. Cir.1991).

damages and reasonable royalties for infringing products.[11] The U.S. International Trade Commission (ITC) promulgated regulations that encourage parties to obtain its advisory rulings on specific design-around alternatives that avoid infringement,[12] and it has judiciously tailored exclusion orders to facilitate design-around.[13] One of the aims of the Hatch-Waxman Act in the U.S. is to encourage generic drug developers to design around the pioneer patents of existing U.S. Food and Drug Administration (FDA)-approved drugs by granting a 180-day period of marketing exclusivity for the first manufacturer of follow-on non-infringing drug product *during the pioneer patent term*.[14]

We chose for this study the most important of Thomas A. Edison's 424 patents on electric light and power generation.[15] The patent was filed with the U.S. Patent Office on November 4, 1879 and entitled "Electric Lamp." It was issued as U.S. Pat. No. 223,898 on January 27, 1880 (hereinafter called "the `898 patent"). The lessons from this more than a century-old case, are fully applicable and valuable today for four reasons. First, this Edison patent was *not licensed* by its owners who instead pursued injunctions,[16] and when these were obtained, closed down infringing manufacturing production. Those who wished to participate in the lucrative market created by Edison's advance had only one option – to design around Edison's claims with the object of producing a non-infringing commercial substitute lamp. Second, the relevant aspects of patent law that govern patent enforcement, actions, defenses, responses, and incentives of industry actors today are substantially the same as those during Edison's day.[17] Third, this Edison case is an excellent illustration of how the accurate empirical evaluation of the market power of a pioneer patent holder should account for possible design-arounds: because the scope and exclusion power of Edison's `898 patent has itself been persistently overestimated, for example as "covering the use of carbon filament as the source of light," this will prove to be an inaccurate and overbroad characterization.[18] Fourth, the advantage of studying the design around Edison's key patent that stimulated new technology development in the electrical arts nearly 130 years ago, is that it enables assessment of long-term effects — how these pioneering technologies became building blocks for inventions made throughout more than a century.

Our design-around study of the Edison patent case provides a roadmap for the kind of information and analysis to be included before one determines that a particular patent or group of patents conferred any market power, or to rebut assertions to that effect. This analytical framework for downstream development to avoid infringement can be

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[11] *See e.g. Astrazeneca AB v. Apotex Corp.*, 782 F.3d 1324, 1334-35 (Fed. Cir. 2015) ("When an infringer can easily design around a patent and replace its infringing goods with non-infringing goods, the hypothetical royalty rate for the product is typically low. The economic relationship between the patented method and non-infringing alternative methods, of necessity, would limit the hypothetical negotiation. There is little incentive in such a situation for the infringer to take a license rather than side-step the patent with a simple change in its technology. By the same reasoning, if avoiding the patent would be difficult, expensive, and time-consuming, the amount the infringer would be willing to pay for a license is likely to be greater.") (Citations and quotation marks omitted).

[12] 19 C.F.R. § 210.79; 19 U.S.C. § 1337(k)(2). In addition, respondents may request a ruling from U.S. Customs and Border Protection that their new designs are non-infringing and thus not covered by an ITC order. 19 C.F.R. § 177.1, et seq. *See also* Merritt R. Blakeslee and Christopher V. Meservy, *Seeking Adjudication of a Design-Around in Section 337 Patent Infringement Investigations: Procedural Context and Strategic Considerations*, 35 AIPLA Q. J. 385 (2007).

[13] See CERTAIN PERSONAL DATA AND MOBILE COMMUNICATIONS DEVICES AND RELATED SOFTWARE, Inv. No. 337-TA-710 (Enforcement Proceeding), Commission Opinion, at 78-83, (USITC Dec. 9, 2011) (HTC received 4 months grace period to introduce non-infringing design-around).

[14] Drug Price Competition and Patent Term Restoration Act of 1984, Pub. L. No. 98-417, 98 Stat. 1585 (1984). The 180-day marketing exclusivity provision is codified in 21 U.S.C. § 355(j)(5)(B)(iv).

[15] Electric Light and Power Patents, *The Thomas Edison Papers*, Rutgers University, *available at* http://edison.rutgers.edu/elecpats.htm.

[16] S. D. Greene, head of GE's lighting division reiterated the injunction and no-licensing policy, "We are… concentrating the energies of our entire legal staff in closing up the manufacturing concerns…" Letter from S D. Greene to the McKeesport Light Company, February 13, 1893 (GE Files) cited in HAROLD C. PASSER, THE ELECTRICAL MANUFACTURERS, 1875-1900; A STUDY IN COMPETITION, ENTREPRENEURSHIP, TECHNICAL CHANGE, AND ECONOMIC GROWTH 157 (Harvard University Press 1953).

[17] The patent law in Edison's time, the Revised Statutes (1874) ("R.S."), have been codified with substantively the same provisions in today's Title 35 of the U.S. Code: R.S. §§ 4886, 4887, 4923 on the requirements for patentability are now at 35 U.S.C. §§ 101-103; R.S. § 4888 on requirements of patent specification is now at 35 U.S.C. §112; R.S. § 4919 on damages for patent infringement are now at 35 U.S.C. §§ 281 and 284; R.S. § 4921 on injunctive relief is now at 35 U.S.C. § 283; and R.S. § 4920 on presumption of patent validity and defenses for infringement are now in 35 U.S.C. § 282.

[18] See note 49 *infra*.

employed by experts to demonstrate the equitable factors that establish whether the issuance of an injunction or an exclusion order against patent infringers is in the public interest.[19]

Our study is an important contribution by shedding new light on Edison's fundamental technical advance and the response of his industry contemporaries. Our detailed temporal analysis of lamp improvements during Edison's time permit us to identify particular events that marked fundamental shifts in designs of incandescent lamps in the market and estimate the delays in the public comprehension and adoption of Edison's advance.

2 Evidence of economic outcomes of design-arounds

As early as 1962, the National Academy of Sciences in its report acknowledged that one of the positive effects of designing around patents "is that new and superior products or processes are frequently developed that probably would not have been developed, at least as soon, in the absence of the need to 'invent around.'"[20] Design around pioneer drug patents under the Hatch Waxman Act is made possible because Congress recognized that patentably-distinct inventions could have therapeutic equivalence (bioequivalence) [21].

Some have theorized that competitors compelled to design around patent claims waste or duplicate R&D resources for achieving the same results as patented inventions [22]. Analytical models have been constructed to account for R&D "waste" by "imitators" who "invent around" the original patent [23], but they have not accounted for the possibility of valuable improvements or new innovations that would not have been otherwise introduced but for the incentives to avoid infringement. Empirical work at the R&D project level (without addressing the role of patent claims) has cast doubt on the "duplication/waste" argument, showing a more complex set of incentives with "multiple prizes" (Cockburn and Henderson 1994).

It has been shown that industry participants are keenly aware of the potential economic value of designing around. When asked about the limitations of patent protection, the ability of competitors to "invent around" both process and product patents was rated higher than five on a seven-point scale of importance by R&D managers in 60 percent of the responding industries [24]. In a survey reported by Otis & Sellers of 282 industry clients of patent attorneys, 57% said they had attempted to design around another's patent. Of these respondents, 61% reported that they had obtained results superior to the patented invention, whereas an additional 26% reported that they had obtained items equal in merit. Only 13% reported coming up with inferior devices. Moreover, 75% reported that invent-around efforts had opened up new fields of R&D, and 78% made additional inventions during the course of those efforts.[25] In another survey of British firms, "almost all" twenty instances of refusals to license under "important" patents resulted in the respondent firm designing around to circumvent the unlicensed patent by the use of existing technology, or by very little incremental

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[19] *See* Ron D. Katznelson, *Comments on the public interest*. IN THE MATTER OF CERTAIN MOBILE ELECTRONIC DEVICES AND RADIO FREQUENCY PROCESSING COMPONENTS THEREOF, Inv. No. 337–TA–1065 (USITC February 9, 2019), *available at* https://bit.ly/ITC-Comments-2019. (Showing that the public interest benefits of designing around the patent claim were the Commission to issue an exclusion order would outweigh any benefits of allowing the importation of infringing products into the U.S. Showing evidence that issuance of the exclusion order will result in design-around the only patent claim at issue. Analyzing respondent's design-around options and identifying incentives for further investments in System on Chip technologies that avoid infringement by eliminating the off-chip data bus. Concluding that enforcement of the patent will promote — not retard — the public interest and consumer benefits, thereby promoting 5G technology development.)

[20] NATIONAL RESEARCH COUNCIL, THE ROLE OF PATENTS IN RESEARCH, PART I 14 (National Academy of Sciences, National Research Council 1962); *See also* KEVIN G. RIVETTE & DAVID KLINE, REMBRANDTS IN THE ATTIC: UNLOCKING THE HIDDEN VALUE OF PATENTS 25 (Harvard Business School Press 2000).

[21] FED. TRADE COMM'N, GENERIC DRUG ENTRY PRIOR TO PATENT EXPIRATION 7 (2002), available at http://purl.access.gpo.gov/GPO/LPS21619.

[22] F. M. SCHERER, INDUSTRIAL MARKET STRUCTURE AND ECONOMIC PERFORMANCE 2nd ed. 446 (Rand McNally College Pub. Co. 1980); FRITZ MACHLUP, AN ECONOMIC REVIEW OF THE PATENT SYSTEM 51 (U.S. Govt. Print. Off. 1958); D. F. Turner, *Patent System and Competitive Policy,* 44 NEW YORK UNIVERSITY LAW REVIEW 450, 455 (1969).

[23] Louis Kaplow, *The Patent-Antitrust Intersection: A Reappraisal,* 97 HARV. LAW REV. 1813 (1984); Nancy T. Gallini, *Patent Policy and Costly Imitation,* 23 RAND J. ECON. 52 (1992).

[24] Richard C. Levin et al., *Appropriating the Returns from Industrial Research and Development,* 1987 BROOKINGS PAPERS ON ECONOMIC ACTIVITY 783 (1987).

[25] Otis & Sellers, *supra* note 8.

R&D investment.[26] A more recent survey providing data from qualitative interviews with innovation practitioners indicates they regard invention around patents as a source of progress. [27]

Other surveys found that the so-called "imitator's" development costs were substantially lower than that of the original innovation [28] and that about 60% of successful patented innovations were "imitated" within four years.[29] Mansfield reflected on the short delay of "imitations" of new products or processes that followed leaks of their technical information within about a year from product launch and concluded that it is because "it is so often possible to invent around patents." [30] Indeed, 65% of respondents in a survey of R&D labs in the U.S. manufacturing sector identified the ease of inventing around as a reason to forgo patent protection,[31] which is also a top-ranked reason for small high technology firms, second only to patenting costs.[32] Similar results were obtained in a survey of Swiss R&D executives, where inventing around patents was ranked as the most important constraint on the effectiveness of patents.[33] Interviews of 70 practitioners in biotechnology fields indicate that research tools that are invent-arounds in the biotechnology industry have also proven beneficial in pharmaceutical research.[34] While the self-reporting surveys described above are important indicators, there is a paucity of published empirical research on achieved design-arounds.

As to product-specific examples of designing around patents, they are known from as long ago as 1796, when Trevithick invented around Watt's steam engine condenser patent with a high pressure engine that needed no condenser.[35] Wallace H. Carothers' nylon patents owned by Du Pont were successfully invented-around by IG Farbenindustrie (IG) with its invention of "nylon-6", U.S. Patent No. 2,241,321.[36] Du Pont's response to the speed and effectiveness of IG's design-around research was to license its nylon patents to IG for use exclusively in Germany and selected European markets in exchange for IG staying out of the US, Asia and the remainder of the European markets.[37] Historical trends in competitive product entry times following selected initial product introductions indicate they were typically sooner than the term of any initial product patent protection.[38] For the same data set, Gort and Klepper provide patenting rates (in Table 8) and recognize that in what they call "Stage 1" of product diffusion, immediately

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[26] C. T. TAYLOR AND Z. A. SILBERSTON, THE ECONOMIC IMPACT OF THE PATENT SYSTEM: A STUDY OF THE BRITISH EXPERIENCE, 183-85, 200 (Cambridge University Press1973).

[27] J. Silbey, *Patent Variation: Discerning Diversity Among Patent Functions,* 45 LOYOLA UNIVERSITY CHICAGO LAW JOURNAL 441, 464-65 (2013).

[28] Edwin Mansfield, Mark Schwartz & Samuel Wagner, *Imitation Costs and Patents: An Empirical Study,* 91 THE ECONOMIC JOURNAL 907 (1981); Levin et al., *supra* note 24 at 811.

[29] Mansfield, Schwartz & Wagner, *supra* note 28 at 907.

[30] Edwin Mansfield, *How Rapidly does New Industrial Technology Leak Out?* 34 THE JOURNAL OF INDUSTRIAL ECONOMICS 217 (1985)

[31] Wesley M. Cohen, Richard R. Nelson & John P. Walsh. *Protecting their intellectual assets: Appropriability conditions and why US manufacturing firms patent (or not).* NATIONAL BUREAU OF ECONOMIC RESEARCH NO. W7552 (2000) (Fig. 5).

[32] Stuart J. Graham et al., *High technology entrepreneurs and the patent system: Results of the 2008 Berkeley patent survey*, 24 BERKELEY TECH. LAW JOURNAL 1255, 1310-11 (2009); JOSEPH J. CORDES, HENRY R. HERTZFELD AND NICHOLAS S. VONORTAS, A SURVEY OF HIGH TECHNOLOGY FIRMS. 58 (Office of Advocacy, U.S. Small Business Administration 1999).

[33] Najib Harabi, *Appropriability of technical innovations: An empirical analysis*, 24 RESEARCH POLICY 981 (1995).

[34] JOHN P. WALSH ET AL., *Effects of Research Tool Patents and Licensing on Biomedical Innovation, in* PATENTS IN THE KNOWLEDGE-BASED ECONOMY 285, 303, 323 (Wesley M. Cohen et al. ed., National Academies Press 2003).

[35] George Selgin & John Turner, *Strong Steam, Weak Patents, Or, the Myth of Watt's Innovation-Blocking Monopoly, Exploded,* 54 JOURNAL OF LAW AND ECONOMICS 841 (2011).

[36] We identified 3 Carothers patents owned by Du Pont with polyamide in the title or abstract (U.S. Patent Nos. 2,071,250, 2,071,251, and 2,071,253) issued before the June 10th, 1938, IG's priority filing date. We analyzed the IG `321 patent specification against the 83 claims in the three Carothers Du Pont patents. We found that the essential limitations of Carothers claims included polyamides as a product of the condensation reaction, others as between *two* reactants, and still other limitations directed at polyamides by defining the general formula for the repeating basic monomer units, subject to a narrower claim construction due to Carothers' own prior art cited in his patent specification. We observed that all these Carothers claims were evaded by the IG nylon 6 process described in the `321 patent. This is because IG had found that the monomer cyclic lactams' rings (for nylon-6, caprolactam) when heated polymerized directly into polyamides (the rings broke open)—without the condensation reaction, with only *one*, and not two reacting monomers. As for Carothers' claims on the general formula for polyamide chains, IG's patented process was on the actual polymerization of the lactams to polyamides, apparently outside the narrow scope of Carothers formula claims.

[37] D.A. HOUNSHELL AND J.K SMITH, SCIENCE AND CORPORATE STRATEGY – DU PONT R&D, 1902-1980. 207 (Cambridge University Press 1988).

[38] Rajshree Agarwal & Michael Gort, *First-Mover Advantage and the Speed of Competitive Entry, 1887-1986,* 44 J. LAW ECON. 161, 177 (2001).

following new product introduction and preceding the onset of rapid competitive product entry, "entry in some markets may be blocked by patents during the early stages of the industry's development."[39] This suggests that at least for some of the initial products, designing around patents probably occurred and enabled early competitive product entry. Beck can be credited with studying specific substitutes created by design-arounds with data from patented technologies in the glass container industry, the oil refining industry, and the shoe machinery industry.[40]

Perhaps the most product-specific empirical accounts of new products designed around pioneer patents are by Joseph DiMasi and colleagues. One study of 235 follow-on drugs for 72 first-in-class (pioneer) therapeutic drug classes found that the average time to competitive entry by such follow-on drugs has been declining steadily from about 8 years in the 1970's to less than 2 years at the end of the 1990's.[41] There can be very little doubt that a substantial number of the 235 follow-on drugs involved designing around the pioneer patent. The passage of the Hatch-Waxman Act of 1984 enabled competitive entry with shorter delays.

The clinical benefits of design-arounds in pharmaceuticals are substantial: approximately one-third of all follow-on drugs have received a therapeutic priority rating from the U.S. FDA[42] and 57% had at least one follow-on drug that received a priority rating.[43]

That the benefits of designing around patents in the pharmaceutical industry are clearly measurable is also highlighted in the U.S. Federal Trade Commission (FTC) Report on generic companies' drug entry prior to pioneer patent expiration.[44] They are not always recognized, however – not even by the same agency that reported on them. In the section "Design-Around Innovation," the FTC patent report remarkably fails to mention the agency's own measurable benefit findings and concludes that "[w]ithout a clear basis for assessing the net value of design-around activity, general conclusions are difficult."[45]

Case studies also show that novel, patented technologies for *substituting* products are not *necessarily* designs-around the advance captured in the patent claims of *existing* patented technology—cases that should be distinguished from invention around specific patent claims in force. Such a case appears to be Chester Carlson's invention of xerography,[46] an implementation of dry electrostatics to substitute for the cumbersome liquid-based process in silver halide photographic methods. The latter were the Photostat (sold by the market leader, the Photostat Corporation), and the Rectigraph, that in the 1930s served the market for copies of original documents.[47]

It is noted that none of the above-cited works provided data on specific product designs, patents or their claims. Nor did they provide any specific technological feature of "substitutes" or "imitations" as compared to the technological attributes of original patented products. In other words, none of these studies identified what patent claims were "designed around" and how. Hence, these studies cannot determine the extent to which patent claims were actually designed around nor identify the resultant technologies, both of which are necessary steps to evaluate the degree of downstream effects attributable to actual design-around. This article addresses the empirical gap in current scholarship by introducing a novel method for identifying and analyzing the beneficial outcomes of inventing around patented technology in the case of Edison's incandescent lamp patent, U.S. Patent No. 223,898. As further described in 4.1, our method also reveals the advantageous claim-scope *regulation* feature of design-arounds not hitherto documented with empirical evidence: this activity stimulates an *early* disclosure of downstream technologies which accelerates the expansion of the prior-art that limits the scope of subsequent exclusive rights.

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[39] M. Gort and S. Klepper, *Time Paths in the Diffusion of Product Innovations*, 92 THE ECONOMIC JOURNAL 645 (1982).

[40] Roger L. Beck, *Patents, Property Rights, and Social Welfare: Search for a Restricted Optimum,* 43 SOUTHERN ECONOMIC JOURNAL 1045 (1976); See critique of Beck's analysis by Daniel L. Landau, *Patents and Over-Investment in Process Inventions? Comment,* 45 SOUTHERN ECONOMIC JOURNAL 285 (1978) and Beck's reply at Roger L. Beck, *Patents and Over-Investment in Process Inventions: Reply,* 45 SOUTHERN ECONOMIC JOURNAL 289 (1978).

[41] J. A. DiMasi & C. Paquette, *The Economics of Follow-on Drug Research and Development - Trends in Entry Rates and the Timing of Development,* 22 PHARMACOECONOMICS 1 (2004)

[42] An approved drug receives an FDA therapeutic priority rating only if it provides significant or modest *gain* over existing therapy.

[43] DiMasi & Paquette, *supra* note 41 at 1.

[44] FED. TRADE COMM'N, GENERIC DRUG ENTRY PRIOR TO PATENT EXPIRATION, at 9.

[45] FED. TRADE COMM'N, TO PROMOTE INNOVATION: THE PROPER BALANCE OF COMPETITION AND PATENT LAW AND POLICY 22 (2003), available at http://purl.access.gpo.gov/GPO/LPS42012.

[46] See U.S. Patent Nos. 2,221,776; 2,297,691; and 2,357,809.

[47] DAVID OWEN, COPIES IN SECONDS 80-111(Simon and Schuster 2004).

3 Edison's '898 pioneer patent – the historical and legal trajectory

Although Edison's patent issued in 1880, a court first signaled to the public that Edison's invention was a basic pioneering invention on October 5, 1889 when Circuit judge Bradly found invalid the Sawyer and Man patent which had been asserted against users of the Edison lamp. He characterized Edison's invention as "the grand discovery in the art of electric lighting, without which it could not have become a practical art for the purposes of general use in houses and cities."[48] However, subsequent characterization of it as "covering the use of carbon filament as the source of light" is inaccurate and overbroad:[49] Edison did not invent nor broadly-claim the use of carbon filament in incandescent lamps, indeed he could not, for carbon filaments in electric lamps had been in use prior to Edison's application for a patent.[50] Inspection of Edison's patent claims confirms that such assertions are misconceptions, as the patent *claims* were, as they are today, the sole measure of the invention and the secured exclusive right in Edison's day.[51]

The four claims in the `898 patent are shown in Figure 1, with relevant emphasis added.

> (1) An electric lamp for giving light by incandescence, consisting of a *filament of carbon of high resistance*, made as described*, and secured to metallic wires, as set forth*.
>
> (2) The combination of carbon filaments with a receiver *made entirely of glass*, and *conductors passing through the glass*, and from which receiver *the air is exhausted*, for *the purposes set forth*.
>
> (3) A carbon filament or strip *coiled* and connected to electric conductors, so that only *a portion of the surface of such carbon conductors shall be exposed for radiating light*, as set forth.
>
> (4) The method *herein described* of securing the *platina contact wires to the carbon filament*, and carbonizing of the whole in a closed chamber, *substantially as set forth*.

Figure 1. The claims of U.S. Patent 223,898 to Thomas A. Edison (emphasis added).

Claim drafting practices developed in view of U.S. Supreme Court decisions at that time employed in the body of the claims the words "as described" or "as set forth" in order to ensure that an overbroad claim construction by a challenger of the patent would not invalidate the claims.[52] This feature of Edison's claims proved significant in sustaining their validity, but also in limiting their scope.

Consequently, only Claim 2 was recognized as having relatively broad scope, covering Edison's basic invention in a manner that was difficult for others to circumvent. Ruling on Edison's patent infringement complaint lodged June 1886, a U.S. district court on July 14, 1891 upheld Edison's patent's validity and found that Claim 2 was infringed by U.S. Electric Lighting Co. ("USEL"),[53] which decision was affirmed on appeal on October 4, 1892.[54] The court considered

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[48] *Consolidated Electric Light Co. v. McKeesport Light Co*., 40 Fed. 21, 29 (C.C.Pa 1889).

[49] This common misconception (for example Merges & Nelson, *supra* note 5 at 885), is likely the source of much unsubstantiated works about the scope of Edison's patent – the idea that Edison "invented the light bulb," that his patent was so basic as to "block others from entering the market," John S. Leibovitz, *Inventing a Nonexclusive Patent System,* 111 YALE LAW J. 2251, 2253 (2002), "limit post-patent innovation," Michael A. Carrier, *Unraveling the Patent-Antitrust Paradox,* 150 UNIVERSITY OF PENNSYLVANIA LAW REVIEW 761, 830 (2002), that during its enforcement, competition "suddenly became impossible," Merges & Nelson, *supra* note 5 at 885 (citing Bright 1949, at 89) and "filament development and lamp development more generally virtually stagnated." Robert P. Merges & Richard R. Nelson, *On Limiting Or Encouraging Rivalry in Technical Progress: The Effect of Patent Scope Decisions,* 25 JOURNAL OF ECONOMIC BEHAVIOR & ORGANIZATION 1, 15 (1994).

[50] The narrower scope of the `898 patent was made legally clear even during an earlier federal court ruling involving Edison's rivals' patent. By clarifying that carbonized fibers of wood or other vegetable material is generally intended to mean "charcoal," the court said: "neither Sawyer and Man nor Edison can maintain any just claim to the exclusive use of charcoal generally, in any form, as an incandescing conductor in an electric lamp." *Consolidated Electric Light Co v. McKeesport Light Co.,* 40 F. 21, 25 (C.C.Pa. 1889).

[51] *Yale Lock Mfg. Co. v. Greenleaf,* 117 U.S. 554, 559 (U.S. 1886) ("The scope of letters patent must be limited to the invention covered by the claim").

[52] *Seymour v. Osborne*, 78 U.S. 516, 547 (1870).

[53] *Edison Elec. Light Co. v. U. S. Elec. Lighting Co*., 47 F. 454 (S.D.N.Y. 1891).

[54] *Edison Elec. Light Co. v. U.S. Elec. Lighting Co*., 52 F. 300 (2d Cir. 1892).

the prior art[55] and held that Claim 2 recited a fundamental invention covering the accused infringing lamps, namely, an incandescent lamp combination with a carbon filament, hermetically sealed in an all-glass chamber exhausted to a practically perfect vacuum, and having leading-in wires passing through the glass. These were the claimed elements around which major attempts to design around were undertaken.

Judge Wallace had concluded that Edison's main invention was grounded not merely in using a carbon burner in vacuum, which was known in the prior art, but that a burner can be made consisting of an extremely thin filament (seven thousands of an inch) of high electrical resistance that can only survive in practically perfect vacuum while serving as a bright illuminant.[56] It is worth noting that the court construed Claims 1 and 4 as directed narrowly to the mode of connecting the filament and therefore it was *not* infringed because the defendant had successfully designed-around these claims by using a substitute method of connecting the carbon filament to the leading-in wires.[57] Similarly, Claim 3 requiring a "coiled" filament was of no infringement concern for simple arc-shaped filaments.

3.1 Edison's advance that unlocked the field of electrical incandescent lighting

Edison did not "invent the light bulb" but his invention of a thin carbon filament of high resistance in a practical electrical illumination system had several technological advantages over the prior art of thick carbon burners; these advantages enabled the achievement of a viable commercial system of electric lighting.

First, the filament's ability to draw small currents due to its high electrical resistance enabled networks of many lamps to be electrically connected in parallel rather than in series, making the operation of each lamp independent of the others. Second, a collateral advantage not immediately appreciated by Edison's contemporaries, was that the low current drawn by Edison's high-resistance filaments virtually eliminated the critical demand on the conductive interface and contact integrity of the bond between the carbon filament and the platinum leading-in wires. This contributed greatly to lamp operational longevity.

The practical significance of these advantages was apparently missed by other lamp developers well after Edison's patent issued. More than 5 months after Edison applied for his patent and 2½ months after it issued, Joseph W. Swan, whose work in Great Britain is sometimes credited with having preceded Edison's invention, filed his first U.S. incandescent lamp patent (U.S. Pat. No. 233,445) employing five relatively wide carbon filaments connected *in parallel* through internal terminals. This had the effect of substantially *reducing* the filament resistance, a continued inferior deviation from Edison's teaching. For nearly two years after Edison's patent issued, others persisted in futile attempts to solve problems inherent only to low electrical resistance, thick carbon incandescent rods that drew high currents and incurred high rates of erosion.[58] Well after Edison's patent issued, Sawyer continued to insist that the resistance of the carbon incandescent rod must be kept as low as possible and so confined his attention to short, thick carbon rods.[59] These efforts were unsuccessful and Sawyer admitted that "many of the lamps failed to last more than a few hours."[60]

In contrast, Edison's results were spectacular, as his lamps had a life span of about 1,000 operating hours,[61] about one hundred times longer than that of lamps by Swan, Maxim, or Sawyer and Man. Beyond the sustained high vacuum single piece glass vessel, a significant factor for this advantage was the result of Edison's exhaustive search and perfection of thin, high resistance carbon filaments - the U.S. Supreme Court acknowledged Edison's research of over

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55 For an extensive survey of the prior art preceding Edison's inventions see LAMP COMMITTEE, THE DEVELOPMENT OF THE INCANDESCENT ELECTRIC LAMP UP TO 1879 (Association of Edison Illuminating Companies 1929). *Available at* http://babel.hathitrust.org/cgi/pt?id=mdp.39015063950409.

56 *USEL*, 47 F. at 460.

57 The defendant was found not to infringe these claims, "if for no other reason, because the leading wires in its lamps are not secured to the filament according to the method of the patent; that is, by cement carbonized in situ, but by clamps such as the specification condemns." *USEL*, 47 F. at 460-61.

58 For example, in the two-year period following Edison's patent issuance, futile continued attempts to solve carbon renewal problems and challenges arising only in the usage of thick carbon pencils were evidenced by the patent applications of: Sawyer (Pat. No. 227,386), for an improved roller contact mechanism for the carbon pencil; Man (Pat. No. 227,118), for a method of preventing the occurrence of an electrical arc in the carbon pencil-to-conductor connection. Other futile inventive efforts can be examined in the patents of: Sawyer and Street (Pat. No. 241,430); Farmer of USEL (Pat. No. 265,790); Hiram Maxim (Pat. No. 252,392); Crosby and Fox (Pat. No. 248,407); Lane Fox (Pat. No. 251,774); Bohm (Pat. No. 250,192) and McTighe (Pat. No. 258,240).

59 BRIGHT, THE ELECTRIC-LAMP INDUSTRY, at 52.

60 WILLIAM E. SAWYER, ELECTRIC LIGHTING BY INCANDESCENCE, AND ITS APPLICATION TO INTERIOR ILLUMINATION. A PRACTICAL TREATISE. 86 (D. Van Nostrand 1881).

61 BRIGHT, THE ELECTRIC-LAMP INDUSTRY, at 134.

6,000 filament compositions[62] – that ultimately converged on the use of carbonized bamboo fibers.[63] Edison patented the bamboo filament in U.S. Pat. No. 251,540 filed on Aug 6, 1880.

It was not until Aug 10, 1881, the opening of the world's first electrical exposition in Paris, that Edison's achievement was recognized and "completely eclipsed" Swan's and Maxim's incandescent lamps, earning him five gold medals and the highest honors.[64] As shown in Section 4 and Figure 5, the belated public recognition and use of the features that imparted the coveted longevity to Edison's filaments shifted much industry effort into the adoption of Edison's basic invention that unlocked the field.

A thin high resistance carbon *filament* – as opposed to a low resistance carbon pencil or rod – was an essential element of Edison's invention. These filaments could only survive over a sufficiently long operating period in extreme vacuum and so Edison invented the one-piece glass globe through which lead-in wires were fused—the only practical solution at that time for maintaining long term leak-proof extreme vacuum for protecting thin filaments. Those who had employed burners of thick carbon pencils or rods prior to Edison's invention had not recognized the need for *maintaining perfect* vacuum – previously all lamp artisans had used air-exhausted but leaky *stopper* globes, or even open-air lamps. Before Edison, no one had combined a "carbon filament with a receiver made entirely of glass, and conductors passing through the glass, and from which receiver the air is exhausted" as recited in Edison's Claim 2.

3.2 Enforcement of Edison's patent

That Edison's invention was understood to be state-of-the-art and of great commercial value is shown by the successful enforcement of the `898 patent on infringers. The permanent injunctions decreed under the *USEL* July 1891 judgment was affirmed on appeal on October 4, 1892. Another suit was then brought in the same court against the Sawyer-Man Electric Company, and a preliminary injunction was granted and affirmed on appeal on December 15, 1892.[65] Infringement suits were then immediately brought against the Westinghouse Electric Company in Pennsylvania,[66] the Perkins Electric Lamp Company and the Mather Electric Company in Connecticut, and the Beacon Vacuum Pump and Electrical Company in Massachusetts,[67] and preliminary injunctions were obtained. By February 1893, the legal and technical contours of Edison's exclusive rights had been fully clarified as to *existing* lamp designs on the market.

Nevertheless, this patent had not conferred on Edison a scope beyond the metes and bounds defined by the essential limitations of the claims. If Edison's `898 patent had any substantive ability to enhance Edison/GE position in the incandescent lamp market, it would have been during the period when injunctions were available from the appeal court decision in October 4, 1892 until the patent's expiration on November 19, 1894. We show no enhancement of market position during the enforcement of Edison's patent, and accelerated development of commercially-significant, non-infringing close substitutes for Edison's lamp.

4 Data and methods

We have used a variety of source material for this study, with emphasis on primary sources from the Thomas Edison Papers collection,[68] patent specifications, legal court decisions, and contemporaneous trade publications. To establish Edison's fundamental technical advance, the design-arounds by his industry contemporaries, and the impact of these design-arounds on downstream development, we employ a novel method. The novelty of our approach is that we first establish objective indicators for an actual design-around through precise product description and patent claim facts, and then through forward patent citation analysis trace technology developed in those specific non-infringing lamp designs as antecedent to downstream technology development.

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62 *Consolidated Electric Light Co. v. Mckeesport Light Co.*, 159 U.S. 465, 472 (1895).

63 ROBERT D. FRIEDEL ET AL., EDISON'S ELECTRIC LIGHT: BIOGRAPHY OF AN INVENTION 156-57 (Rutgers University Press 1986); ROBERT E. CONOT, THOMAS A. EDISON: A STREAK OF LUCK 173-75 (Da Capo Press 1986).

64 CONOT, THOMAS A. EDISON: A STREAK OF LUCK, at 188-89.

65 *Edison Electric Light Co. et al. v. Sawyer-Man Electric Co.*, 53 F. 592, 599 (2nd.Cir.1892).

66 *Edison Elec. Light Co v. Westinghouse Elec. & Mfg Co*, 54 F. 504, 504 (C.C.W.D. Pa. 1893).

67 *Edison Elec. Light Co. v. Beacon Vacuum Pump & Elec. Co.*, 54 F. 678, 693 (C.C.D. Mass. 1893).

68 Throughout this paper we often refer to online resources of the Thomas Edison Papers collection by an alphanumeric string hyperlinked to particular records. The reader can use the alphanumeric reference string in the "Document ID" field in the form at http://edison.rutgers.edu/singldoc.htm to retrieve the image of the reference.

4.1 The schematic overview of our analysis

We do not find this approach in other work, so we developed Figure 2 to illustrate the structure of our analysis. We begin with the original product (**A**) and it's associated patent claims, which in our case is the Edison's claims in the `898 patent. Having identified the patent claims of **A**, we identify with particularity the products or processes (such as **B**), designed around the original patent claims of **A**.

This paper is concerned with the identification of design and inventions-around the patent claims of **A,** which include conceived product designs **B,** both undeveloped and developed. In Figure 2, products **B** are indicated as avoiding the claimed subject matter of **A**'s patent (dark gray), while being enabled in part by: the *unclaimed* subject matter described in **A**'s patent (light gray), the subject matter already in the public domain (white), and novel subject matter described in **B**'s own patent (both dark and light gray). In general, a design-around would not necessarily require invention; in the Edison case many did require inventing-around and indeed, we chose to identify design-arounds (alternative lamp designs) *by* the invention around patents that made them conceivable. Our method of determining products **B**, the designs around Edison's `898 patent (alternative lamp designs described in patents), is detailed in steps 1 – 4 in Section 4.

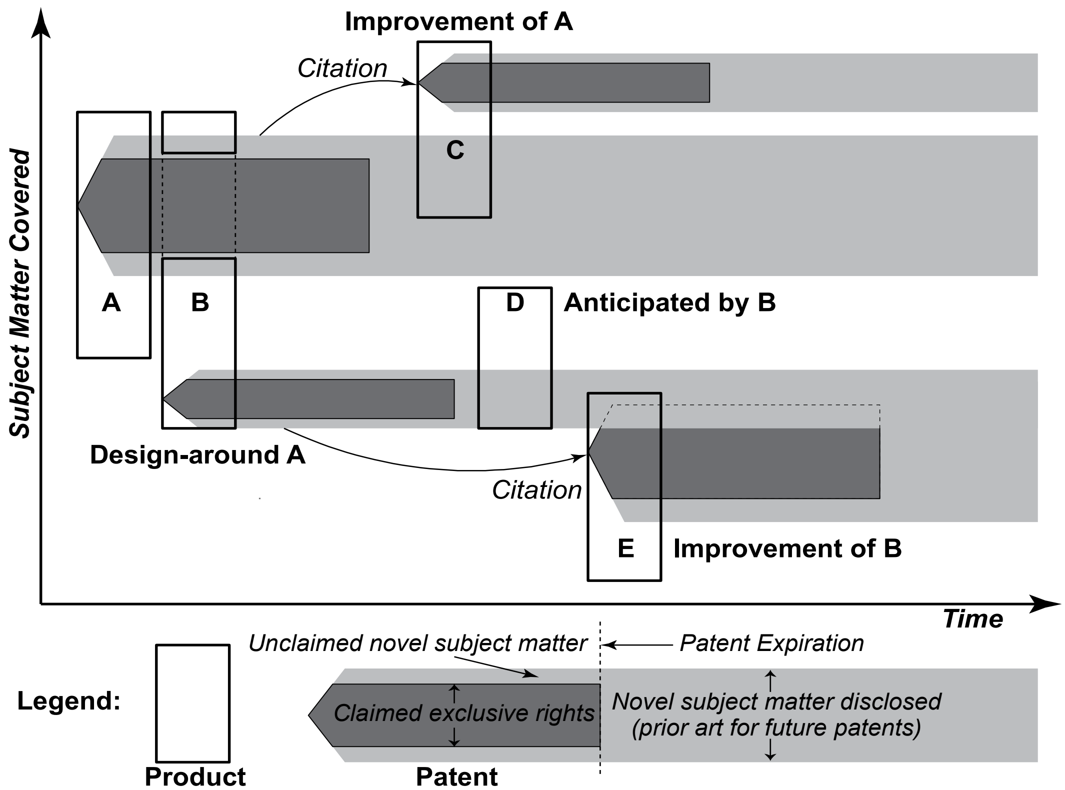

Figure 2. The patent scope and temporal relationship between an original invention (first embodied in Product **A**), a patented product **B** shown as "surrounding" the claimed subject matter of **A** (designed around **A**'s patent), and an improvement by Product **C** introduced after **A**'s patent expiration. Subject matter described in **B**'s patent may limit future downstream claim breadth (in the case of **E**'s patent), or block issuance of later patent claims altogether (as in product **D**).

The second original feature of our study concerns the technological influence of product **B**'s invention around **A**'s patent downstream in time from **B**. In Figure 2, we note that further downstream from **B**, new products or processes may be developed (**D** and **E**) as variants or improvements on **B**. Figure 2 illustrates (by reference to the vertical axis) that the *claimed* subject matter of patents of products **B** must be distinct from the subject matter of product **A** and **A**'s patent; they may constitute radical, pioneering inventions in their own right. To assess such invention-around patents' influence on downstream technology development we adopted a novel cascade form of forward citation analysis.

Patent and technical paper citation analyses have been used to analyze relations between patented technologies using backward or forward citations.[69] Backward citations are citations made by a patent to previously issued patents. Forward citations are citations received by a patent from subsequently issued patents. In contrast to backward citations, the number of forward citations changes over time, even beyond the patent expiration. These types of citations are shown in Figure 2 as **C**'s patent citing **A**'s patent.

Our method for tracking the technological influence of designs around product **B**'s patents is outlined in steps 5 and 6 in Section 4: we track the influence of product **B** downstream based on its patent(s) citations in other later patents, technical papers or legal patent proceedings. Referring to Figure 2 again, we aim to identify downstream products and technologies **E** because **E** cites **B**'s patent, thus indirectly and collaterally linking **E** to **A**.

Figure 2 also illustrates a feature of patent citation not generally appreciated or used by economists who engage in patent citation analysis: a citation in a later patent often means that the claims issued in that later patent were distinguished or narrowed in prosecution so as to claim only subject matter that cannot be *anticipated* by, and is non-obvious *in view* of, the prior art citation. Thus, Figure 2 illustrates how subject matter first disclosed in **B**'s patent can limit future downstream patent claim breadth (as shown in Figure 2 for the case of **E**'s patent), or even block issuance of patent claims altogether (as shown in Figure 2 for product **D** that has no related patent). We show this process in specific cases linked to the Edison patent. Thus, our analysis demonstrates an inherent claim-scope *regulation* feature of the patent system not hitherto documented with empirical evidence: the prior-art limiting patent **A**'s scope, enables others to invent around it – an activity that stimulates new downstream technologies (**B**), which in turn form prior-art that limits the scope of subsequent exclusive rights of improvers (**D** and **E**). We provide illustrative examples in Section B1.2 in the 1901 case denying a patent to Verley for product **D**, and in Section B1.3 in the 1919 case limiting the scope of Langmuir's patent for **E**.

It is generally observed that forward citation frequency of a given patent declines with elapsed time after its issuance.[70] We would therefore expect the largest number of forward citations of the patents in our selection to be in downstream patents issued in the late 1890's and the first few decades of the 1900's. Unfortunately, until 1947, U.S. patents were issued without the citations of the references considered by the examiner in prosecution.[71] The only pre-1947 citations that can be obtained are those cited by applicants in the patent's written description itself and we identified all of those through exhaustive searches in the texts of all U.S. patents issued before 1947.

The total number of examiner-citations to prior art are generally more numerous than all those appearing in patent specifications. Therefore, many patents that issued before 1947 for which examiners considered our selected design-around patents as prior art were undiscoverable. Our study is therefore a conservative illustration of the influence of design-arounds as prior art in after-arising patented technologies.

4.2 Analysis procedure

For identifying design-around activity, we need descriptions of lamp products in Edison's day that are precise enough to permit a determination of whether or not they employ Edison's claimed invention and to further ascertain the precise dates such products were developed. It turns out that the most reliable and complete source for such information can be found in the specification published in patent applications. Those contain detailed technical descriptions of specific products and their filing dates are excellent proxies for the dates of such inventions and product development. Such dates must have been proximal because under the patent law, Section 4886, Revised Statutes of 1874, an inventor who failed to diligently file the patent application after the invention had been reduced to practice would have forfeited the patent right. Not all patent *applications* from Edison's era are observable today but all those that issued as patents are. It is this universe of *published* product descriptions in the field of incandescent lamps that forms the basis for our study. Our data was collected and processed through the six steps enumerated below.

1. Edison patent claim chart. We analyzed Edison's `898 patent claims (listed in Figure 1), using the contemporaneous legal construction given to them by the court decisions and identified Edison's essential claim limitations in the leftmost column of Table 2. This identification method is an objective standard claim-chart technique employed by patent practitioners and litigators.

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[69] B. H. Hall, A. B. Jaffe & M. Trajtenberg, *The NBER Patent Citations Data File: Lessons, Insights and Methodological Tools,* NBER WORKING PAPER NO. W8498 (2001), *available at* www.nber.org/papers/W8498.pdf.

[70] A. C. Marco, *The Dynamics of Patent Citations,* 94 ECONOMICS LETTERS 290 (2007); Hall, Jaffe & Trajtenberg, *supra* note 69.

[71] U.S. PATENT COMMISSIONER, ANNUAL REPORT OF THE COMMISSIONER OF PATENTS TO THE SECRETARY OF COMMERCE FOR THE FISCAL YEAR ENDED 1947 169 (Government printing office 1947)

2. Identification of patents through their classification. A patent classification is a system for categorizing documents, such as patents and published patent applications, according to the technical features of their content. The Patent Office identifies on the face of a patent the classes and subclasses to which it belongs. We began by identifying the patent classes and subclasses for electric lamps (excluding arc lamps) and related components and methods of making them as currently classified under the U.S. Classification system of the U.S. Patent Office. The classes and subclasses so identified are described in detail in Appendix A; we found 392 issued U.S. patents filed between 1830 and 1899 that are classified in these electric lamp classes. We ordered them by filing date and produced the cumulative temporal counts shown in Figure 4 by class category, and in Figure 5, by ownership and subject matter as further described below. The ordered list of these patents is provided online in the data supplement posted on this journal's web page.

3. Partitioning lamp designs by infringement analysis. Patenting activity, as exhibited by the number of patents issued in a given field, is often an objective proxy, indeed a measure, of technical development activity in that field. We employ a novel method to establish a running cumulative count of patents in three design categories by application date with the expectation that any significant changes in the filing rate of patents in each design category before and after our key events may indicate that the event has altered the incentives to engage in that lamp design category. To determine whether other patent applicants' lamp designs circumvented Edison's patent claims, we focused on designs as found in the description (but not as *claimed*) in the patents and partitioned the 392 patents in our electric lamp classes into three design category subsets depending on whether the designs would have infringed Edison's claims – that is, designs that used all elements of at least one of his patent claims. The partition is shown in separate plots in Figure 5 as follows:

(i) Patents labeled "*Edison/GE*" (99 patents) are those naming Edison as the inventor or those expressly assigned to the Edison Company or GE, invented by his known employees. The remaining 293 patents invented by or assigned to others we classified as "other manufacturers" and split in two categories as described in (ii) and (iii) below.

(ii) Patents labeled "*Other Mfrs. Non-infringing*" (103 patents) describe lamp designs that *do not use Edison's claimed invention.* These include designs around Edison's claimed invention (determined as set forth below), and prior art to Edison's invention that, by definition, cannot infringe on Edison's claims.

(iii) Patents labeled as "*Other Mfrs. Other than non-infringing*" (190 patents) are all those not in categories (i) or (ii) above. These patents describe lamp design features that may be used in lamps constructed as per Edison's invention, including designs that should be considered to infringe at least one of Edison's claims. It also includes patents that do not describe subject matter directed to any lamp construction features of Edison's invention.[72]

With respect to subset (ii) above, readily observable design features as described in the patent specifications including the drawings evidencing design-around a feature of Edison's patent claim were identified under the six category conditions **(a)**-**(f)** listed in Table 1. Whether any such design feature is described in the patent requires a mere factual determination that does not involve patent law expertise. Using the conditions **(a)**-**(f)** in logical combination as expressed in the last row of Table 1 for each patent specification, we identified non-infringing designs and have consistently applied the same objective criteria across all patent specifications under study to produce the partition of (ii) and (iii) listed above. These criteria are objective proxies of infringement or non-infringement rulings, had they been made.[73] This claim feature analysis is in line with the standard infringement analysis procedure required by federal courts using a claim "chart identifying specifically where and how each limitation of each asserted claim is found within each Accused Instrumentality."[74]

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[72] For example, patents disclosing methods for making filaments, for evacuating glass lamp globes, or for improved sealing of lamps – none of which pertain to avoiding Edison's claims per se.

[73] Two exceptions we found in which the manufacturers/inventors' interpretation of Edison's claim had been inconsistent with that of the courts are the Waring and Pollard lamps discussed below. We nevertheless categorized these as "non-infringing" because that was the express affirmative defense pled in court, even though the courts later ruled that they infringed Edison's claim.

[74] *See* Patent Local Rule 3-1(c) N.D. Cal. (at www.cand.uscourts.gov/filelibrary/177/Patent_Local_Rules_1-2017.pdf#page=5); E.D. Tex. (at www.txed.uscourts.gov/?q=patent-rules).(Using claim features charts to show infringement).

<table>
<tr><th>Element</th><th>Condition</th><th>Observable Design Feature</th><th>Examples</th></tr>
<tr><td rowspan="2">Lamp filament</td><td>(a)</td><td>Comprises non-carbon material</td><td>See B1.4</td></tr>
<tr><td>(b)</td><td>Not coiled</td><td>See B1, all open arc configurations</td></tr>
<tr><td rowspan="2">Lamp “receiver,” enclosure</td><td>(c)</td><td>Comprises non-glass material</td><td>See B1.1</td></tr>
<tr><td>(d)</td><td>Non-vacuum, gas-filled</td><td>See B1.3</td></tr>
<tr><td rowspan="2">Conductors powering filament</td><td>(e)</td><td>Not passing through the glass</td><td>See B1.2</td></tr>
<tr><td>(f)</td><td>Not carbonize-cemented to filament</td><td>Secured by clamps to filament</td></tr>
<tr><td colspan="4">Lamp design does not-infringe Edison’s patent:
IF (a) is met (avoiding all four claims);
ELSE,
IF [(c) OR (d) OR (e)] are met (avoiding Claim 2);
AND IF (b) is met (avoiding Claim 3);
AND IF(f) is met (avoiding Claims 1, 4)</td></tr>
</table>

Table 1. Observable lamp design features used to determine non-infringing lamp designs.

For example, for condition **(a)**, determining whether a non-carbon filament is specified, or for condition **(e)**, whether the leading-in wires are shown as passing through the glass, require objective factual determinations. The objective determination for condition **(e)**, for example, is based on the drawings and the written description in the subject patent's specification as seen in Appendix B1.1, Figure 9. The partition we obtain for the 392 subject patents into these distinct categories is provided by patent number in the supplemental spreadsheet available on this journal's web page. We provide the results and a summary of such an analysis of product descriptions of the subject patents in the partitions shown in Figure 5 and in Table 2.

4. Selection of non-infringing designs. We selected a representative subgroup of patents from subset (ii) above ("*Other Mfrs. Non-infringing*") for forward citation analysis. The selection was from patents filed in the period from the date Edison asserted his patent to the patent's expiration (1886-1894) based only on one or more of the following criteria:

(i) The patentee, assignee or beneficiary of the subject patent was a known Edison/GE competitor.

(ii) Commercial information on the lamp described in the subject patent was available from other contemporaneous publications such as trade or technical articles.

(iii) The product described in the subject patent was alleged to infringe Edison's patent in litigation.

5. Categorization by the claim element designed around. We further partitioned this patent selection of item **4** above according to which of the claim elements of Edison's `898 patent were circumvented by the product described in the subject patent. We chose at least two patent examples for each claim element and the result (22 patents) is in Table 2. This exemplary list is not exhaustive, as our goal was not to identify *all* attempts to design around Edison's claims, but to illustrate the relation between Edison's patent claims, the inventions that resulted from efforts to design around them, and the possible benefits of such efforts for downstream development.

6. Forward citation of the non-infringing designs. We proceeded with a forward citation analysis of these 22 patents by searching for citations to these patents in the following patent or legal publications:

(i) **U.S. patents**, reference section and any mention in the specification. We used the online electronic databases from LexisNexis®, U.S. Patent Office, Google Patents, and FreePatentsOnline.com.

(ii) **Official gazette of the U.S. Patent Office,** for decisions on interferences, and appeals to the Commissioner of Patents.

(iii) **The Federal Reporter** (Westlaw) and LexisNexis for federal court decisions.

The number of downstream citations found for each patent in our selection is shown at the second rightmost column in Table 2. For all but one patent that had no forward citation, the details of the citing patents and cases are given in Appendix B2.

4.3 Statistical Analysis

We used the subset of "Other than non-infringing" designs as the control on patenting activity of "Non-infringing" designs because the former includes all patents in all relevant lamp classes excepting only the non-infringing designs that we study. This control is optimal, as these patents were classified in the same classes and subclasses of incandescent lamps as the "Non-infringing" patent group. Both categories exclude the Edison/GE patents. The control is also efficient because, but for the effects under study, general exogenous economic influences such as market demand advances in manufacturing methods and other incandescent lamp market conditions should be expected to affect both control and "Non-infringing" patenting rates alike.

Appendix D provides the full details of our statistical analysis. We partition the 19-year observation period since Edison's patent issued in 1880 into six distinct epochs T_e, $e = 1, 2, \ldots, 6$ as shown in broken line epoch boundaries of Figure 5 and also identified in the top rows of Table 6 of Appendix D. As customary in modeling integer counting processes, we treat patent counts in a given time period as discrete integer random variables modeled as having a Poisson probability distribution.[75] This is particularly appropriate when the counts are small in some periods. We denote the total patent counts accumulated within epoch e as random variable integers $\boldsymbol{n}_e$ and $\boldsymbol{m}_e$ for patents describing non-infringing incandescent lamp designs and for all other designs (the "control") respectively. Our model specification provides for distinct underlying patenting intensities Λ_e and Γ_e as governing the observable counts $\boldsymbol{n}_e$ and $\boldsymbol{m}_e$ respectively, each having the Poisson probability density:

$$\text{(1)} \qquad \begin{aligned} \Pr\{\boldsymbol{n}_e = n\} &= f_{\boldsymbol{n}}(n;e) = \frac{\Lambda_e^n}{n!}\exp(-\Lambda_e)\,; \\ \Pr\{\boldsymbol{m}_e = m\} &= f_{\boldsymbol{m}}(m;e) = \frac{\Gamma_e^m}{m!}\exp(-\Gamma_e)\,; \end{aligned} \qquad \text{where } e = 1, 2, \ldots, 6\,.$$

For example, the quantity $f_{\boldsymbol{n}}(n;e)$ represents the probability that a given underlying patenting intensity Λ_e will produce n observed patents filed during the epoch e.

Although under this model, the underlying intensities Λ_e, Γ_e, Λ_{e-1}, and Γ_{e-1} may be numerically related, we assume that the individual random counts $\boldsymbol{n}_e$, $\boldsymbol{n}_{e-1}$, $\boldsymbol{m}_e$, and $\boldsymbol{m}_{e-1}$ are *statistically* independent for the reasons described in Appendix D.

Thus, as further detailed in Appendix D, for each of the five epochs we apply Difference-In-Difference ("DID") analysis to study the changes in patenting intensities: the null hypothesis $\boldsymbol{H_0}$ assumes that introduction of "Non-infringing" lamp designs are made alongside lamp designs "Other than non-infringing" (control), in the same relative proportions before and after a particular legal event pertaining to Edison's patent. Indeed, if that *relative* proportion is unchanged significantly, this means that any changes in patenting intensities of "Non-infringing" lamps tracked the changes in the control and are therefore unrelated to, or not caused by, the respective legal event. For example, such across-the-board patenting intensity changes could be due to increased market interest in electric lighting generally, unrelated to the enforcement of the Edison patent. In contrast, under the alternative hypothesis $\boldsymbol{H_1}$, a disproportionate relative change in patenting intensity of "Non-infringing" designs occurs, breaking significantly from the relative change in the control subsequent to the respective legal event, indicating a significant *shift* in Edison's rivals' preference towards providing "Non-infringing" lamp designs rather than designs infringing on Edison's patent. A finding that such shifts occur only after such an event (*e.g.*, a court decision) is plausible because it is at that point in time that rivals learn with more certainty the legal claim boundaries around which they must design to avoid infringement.

We entertain two distinct groups of hypotheses with respect to observed temporal breaks in patenting intensities between consecutive epochs $e-1$ and e. As further explained in Appendix D, we state the hypotheses in our DID analysis as follows:

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[75] Jerry Hausman, Bronwyn H. Hall & Zvi Griliches, *Econometric Models for Count Data with an Application to the Patents-*R *& D Relationship,* 52 ECONOMETRICA 909 (1984).

H$_0$(*e*): the change in the underlying patenting intensity Λ of "Non infringing" designs tracked proportionately the change in the intensity of the control, Γ, meaning that the respective intensities during the consecutive epochs $e-1$ and e, are related by: $\Lambda_e = \Gamma_e \Lambda_{e-1} / \Gamma_{e-1}$.

H$_1$(*e*): the underlying patenting intensity Λ of "Non infringing" designs changed between the consecutive epochs $e-1$ and e to a value other than that explained by ***H***$_0$(*e*).

Under conventional statistical hypothesis testing practice, for each epoch $e \geq 2$, we test hypotheses ***H***$_1$(*e*) against ***H***$_0$(*e*), with detailed results shown in Appendix D. We discuss the implications of these results in 5.1.

4.4 The limitations of our study

As explained above in Section 4, our present analysis is limited to design-arounds for products documented in the specifications of subsequent patents. Using these sources, we cannot capture design-arounds that did not involve patented products and we note that for the era of the 1890s, documentation of the construction of electric lamp products by date of introduction is largely unavailable.

Another limitation is that our method does not discern whether the actual *product* (if it existed) would have been *judged by a court* as non-infringing, or whether the design was *intended* as a circumventing design-around – inevitably our call is in hindsight. Nevertheless, based on established infringement analysis methods, we are able to determine with a high degree of certainty whether a design appearing in a patent document does not employ the essential elements of Edison's patent claims. This certainty is a cornerstone of our study's contribution.

5 Results

5.1 Incandescent lamp patenting rates before, during and after the enforcement period of Edison's patent

The patenting activity depicted in Figure 3 including the table showing the number of patents filed in the respective time periods, illustrates our key results for incandescent lamp patenting count by design category of manufacturers other than Edison/GE, before, during, and after the enforcement of Edison's `898 patent. It shows a substantial surge in patenting of non-infringing lamp designs (in parallel with a decline in other than non-infringing designs) during the enforcement of the Edison patent. It is followed by a substantial decline in such patenting after the Edison patent expired.

Disclosed designs in patents by all Mfgrs' other than Edison/GE	Filing period	From public exhibition to patent enforcement	Patent Enforcement Period	Post patent expiration
	Start Date	10-Aug-1881	4-Oct-1892	10-Nov-1894
	End Date	4-Oct-1892	10-Nov-1894	1-Jan-1899
	Duration (years)	11.16	2.13	4.12
Non-Infringing Designs	Number of patents	34	36	9
	Mean rate (Pats./Year)	**3 (0.42)**	**16.9 (2.25)**	**2.2 (0.58)**
Designs Other than Non-Infringing	Number of patents	140	7	14
	Mean rate (Pats./Year)	**12.5 (0.85)**	**3.3 (0.98)**	**3.4 (0.72)**

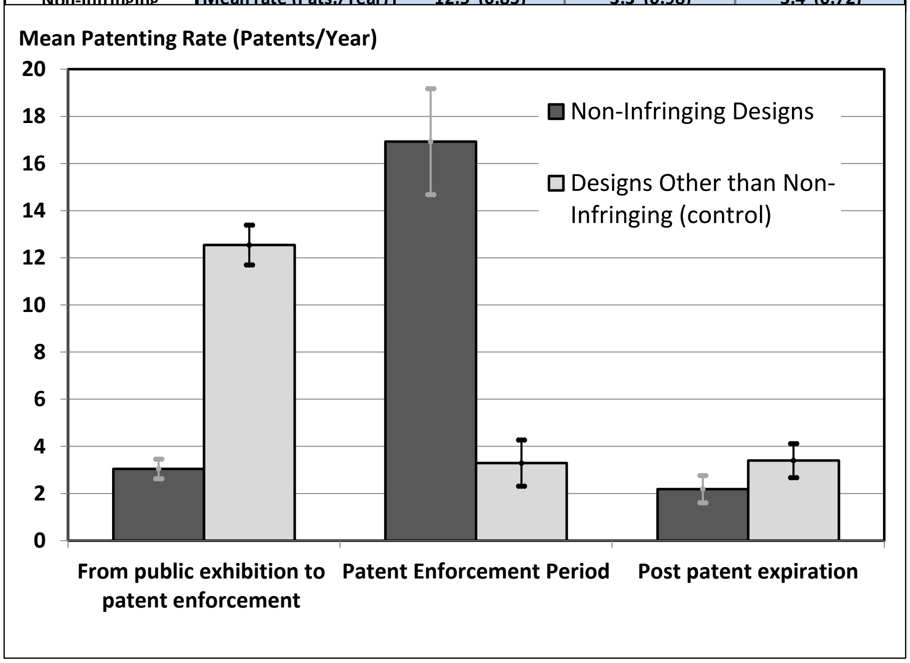

Figure 3. Incandescent lamp patenting rate by design category of manufacturers other than Edison/GE before, during, and after the enforcement of Edison patent. Values of mean absolute deviations as derived in Appendix D are shown in parenthesis and by the error bars in the plot.

We plot patenting activity using the cumulative count of patents by their respective application filing date. A unit step in the graph is shown at the application filing date of each patent issued in the classes. We use this graphical method for patenting rates following the work of Katznelson & Howells on the early aircraft industry,[76] and on the early radio industry.[77] Figure 4 and Figure 5 show the cumulative electric lamp patenting activity for patents filed from 1878 to 1898, inclusive. Figure 4,shows the total patenting count and a breakdown by patents for lamps per se (apparatus), patents for a process, method, or instrument for making lamps, or both, as defined in Appendix A. Figure 5 displays the same patents as Figure 4, but categorized by patentee: Edison/GE and two other design categories defined as "Other manufacturers" subdivided into the two categories - "Non-infringing" and "Other than non-infringing" as described in Section 4.

The "ramp" rate, or the average slope in the graph over a given period, is proportional to the patenting rate (number of patent applications in the category per unit time) during the period. We partitioned the 19 years following the issue date of Edison's patent into 6 epochs for analysis as shown in Figure 5. As fully detailed in Appendix D, for each epoch we tabulate the total patent counts in Table 6. The average patenting rate obtained by dividing the patent counts over each epoch by its duration is also provided in Table 6.

[76] Ron D. Katznelson and John Howells, *The Myth of the Early Aviation Patent Hold-Up — How the U.S. Government Commandeered Pioneer Patents*, 24 INDUSTRIAL AND CORPORATE CHANGE, 1 (2015).

[77] John Howells and Ron D. Katznelson, *The Coordination of Independently-Owned Vacuum Tube Patents in the Early Radio Alleged Patent "Thicket,"* (2015). Available at SSRN: http://dx.doi.org/10.2139/ssrn.2450025.

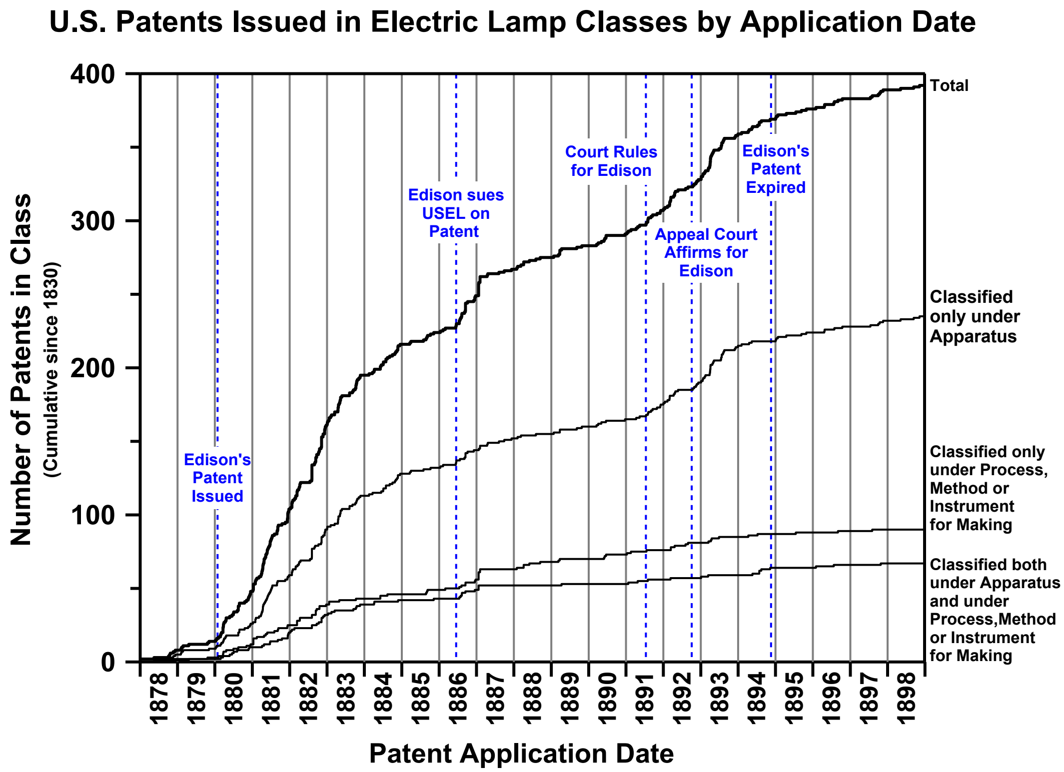

Figure 4. Patenting activity within electric lamp Classes 313 (apparatus) and 445 (process, method or instrument for making) in the relevant subclasses therein, as described in Appendix A. Source: USPTO online database.

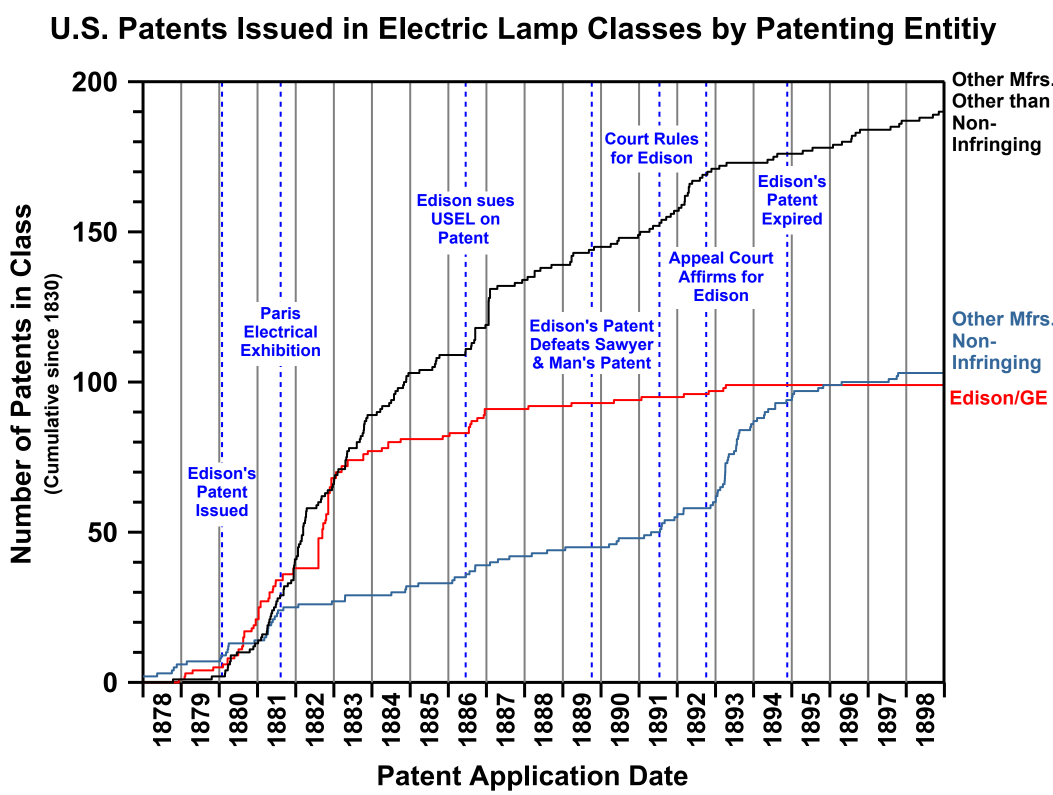

Figure 5. Patenting activity in electric lamp classes shown in Figure 4, categorized by ownership and design.

The temporal relationship of the observed patenting surges to the key legal events of Edison's patent enforcement is remarkable and we infer that a strong causal relation existed between the events indicated in the figures and the patenting surges. Nevertheless, our research of the literature found no alternative events and explanations that could explain the temporal shifts of these observed surges.

For each epoch $e \geq 2$, we test hypotheses $\boldsymbol{H}_1(e)$ against $\boldsymbol{H}_0(e)$, as explained in 4.3, with detailed results shown in Appendix D. With reference to the three patenting categories, their trajectories shown in Figure 5, we make the following observations on the nature of the causal relationship:

(a) Major shifts in patenting activity first occurred only after the 1881 exhibition. Immediately after Edison's patent published in 1880, patenting activity of other manufacturers continued to develop the established technology of lamps of prior-art, ("Non-infringing," epoch 1). However, after the Paris Electrical Exhibition in August 1881 advertised Edison's invention's practical advantages more broadly to the industry, these activities comparatively slowed down substantially (p value ≈ 0, Table 6, epoch 2) and were displaced by patenting activities of other manufacturers involving variants within the scope of Edison's patented technology ("Other than Non-infringing").

(b) A rise in patenting activity in all categories after Edison files suit in 1886. A substantial brief rise in patenting activity ensued after Edison filed an infringement suit under the `898 patent against USEL on June 11, 1886.[78] We detect an increase in the patenting rate of other manufacturers' non-infringing designs but we cannot statistically distinguish the break in such patenting rate from that observed in the other manufacturers' activity of the "Other than Non-infringing" category, which we use as the control (p value of 0.07, Table 6, epoch 3). We also observed that while both Edison and other manufacturers were responsible for the rise in patenting activity, remarkably, many other manufacturers' patent applications described improvements to lamp designs that were clearly *not* aimed at circumventing Edison's claims.

(c) No significant change in patenting activity after Edison defeated the Sawyer & Man patent in 1889. Despite the court ruling holding the Sawyer & Mann patent invalid in October 1889 and declaring Edison's invention "the grand discovery in the art of electric lighting," other manufacturers were not deterred by the Edison patent, on which there was no final decision on appeal in the Edison suit against USEL until October 1892. In this period to 1892, the patenting intensity of "non-infringing" designs changed in a way that cannot be significantly distinguished from the growth of the "control," as the null hypothesis posits, a proposition which we are unable to reject (p value of 0.17, Table 6, epoch 4).

(d) A surge in patenting "Non-infringing" designs after the 1892 affirmance of Edison's patent validity. A precipitous surge in other manufacturers' "Non-infringing" patenting rate followed the affirmance on October 1892 of the ruling in favor of Edison/GE. The increase in patenting intensity is well-differentiated from, and cannot be explained by, changes in the patenting intensity of the Control (p value ≈ 0, Table 6, epoch 5). In fact, as Figure 5 shows, it appears that for other manufacturers, the "Non-infringing" activity displaced the "Other Mfrs. Other than Non- Infringing" activity (the Control). While a few patent filings of "Non-infringing" designs occurred within a few months, a separate time series analysis (not included here) reveals that the brief "Non-infringing" patenting rate surge declined exponentially with a time constant of 1.4 years, all but subsiding by the expiration of Edison's patent.

(e) Decline in patenting of "Non-infringing" designs after Edison's patent expiration in 1894. The "Non-infringing" patenting intensity declined substantially after the expiration of Edison's patent on November 1894 in sharp distinction from the Control patenting rate (p value ≈ 0, Table 6, epoch 6). We infer that with the expiration of the patent there was no longer a motivation to invent around its claims.

5.2 Further investigation of the significant patenting surges

Observation (**b**) above indicating patenting rate increases in all categories appears non-specific as to the `898 patent, perhaps because it was not the only patent asserted at that time. Edison's amended complaint of June 1886 against USEL alleged infringement of additional U.S. patents Nos. 223,898, 227,229 and 265,777 and at that time it had not yet become clear which of the Edison lamp patents would prove a fundamental contested case. Also, on October 7, 1886, the Edison Electric Light Company issued a formal industry open circular to all electric light station operators in

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[78] Edison's original complaint in the suit against USEL filed on May 2, 1885 asserted only Patents Nos. 265,311 and 251,554, the claims of which covered only lamp plugs and socket construction. (See QD0120000A). It was not until June 11, 1886 that Edison's Amended Complaint dropped these patents and asserted instead, the filament Patents Nos. 223,898, 227,229 and 265,777. (See QD012B0001).

which 8 additional Edison lamp patents and other socket patents were specifically identified as being widely infringed.[79] Indeed, we generally noted a wider variety of subject matter developed in the 1886 patenting surge than in the post-1891/92 surge, the latter consisting mostly of designs around the first two claims of Edison's `898 patent and dominated by apparatus patents. In contrast, based on the classifications shown in Appendix A, Figure 4 shows that the patenting surge after 1886 involved patents for processes, methods or instruments for making lamps rather than patents for lamp apparatus proper, indicating general progress with no specific motivation to circumvent Edison's claims. Thus, the surge of 1886 included patents for novel glass globe manufacturing technique, improved sealing of leading-in wires and new methods of securing carbon filaments to the platinum leading-in wires.

Observation (**d**) above as presented in Figure 5 shows our result of novel significance — that non-infringing lamp developments accelerated following the 1891 court decision and most vigorously immediately after the appellate affirmance of October 4, 1892.[80] This is consistent with comment by contemporaries that enforcement of the '898 Edison patent and GE's refusal to license others "has had the effect of stimulating the inventive capacity of the electricians employed by rival interests, with the result that at least two new types of lamp have been put upon the market, which apparently bid fair to be commercially successful, while it is, to say the least, extremely doubtful whether the courts will pronounce either of them to be infringements of the patent. In one of the new lamps the neck of the globe is closed with a separate stopper, instead of being formed integrally, as in the Edison lamp, and in the other a fusible cement is made to serve the same purpose."[81]

A counterfactual interpretation of this result would be that a patenting surge ensued in the early 1890's when investments in lamp research and developments were made. Following the formation of GE in 1889, its merger in 1892 with Thomson-Houston Electric Company, and the 1891 and 1892 court decisions in favor of Edison/GE may have signaled the value and market prospects of incandescent lamp technology in general.

This counterfactual is not a credible interpretation because the change in patenting of "non-infringing" designs in the relevant period is at a statistically-significant higher intensity than the change of the control of "Other than non-infringing" designs. Under the counterfactual interpretation of general elevated interest in development, there would have been no reason to favor patenting "non-infringing" designs. Indeed, the patenting intensity in epochs 3-4 as described in observations (**b**) and (**c**) above *are* consistent with *general* elevated interest in development as posited by the counterfactual interpretation, because during *these periods* there were no statistically-significant differences between changes in patenting intensities of "non-infringing" and "Other than non-infringing" designs. "Other than non-infringing" includes all patented designs classified in all relevant lamp classes *excepting only the non-infringing designs that we study*. This control is optimal, as these patents were classified in the same classes and subclasses of incandescent lamps as the "Non-infringing" patent category. Both categories exclude the Edison/GE patents so they record the choices of firms other than Edison/GE. The statistical differentiation of "non-infringing" designs from "other than non-infringing" must be interpreted as all incandescent lamp developers responding to the 1891-1892 court decisions by realizing the importance of non-infringing designs compared to designs that infringe on Edison's patent and succeeding in patenting such non-infringing designs.

Review of the non-infringing lamp designs is summarized in Table 2, showing the techniques used to bypass the essential limitations of Edison's claims.

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79 E. H. Johnson, *The Edison electric light: the legal and commercial status*, Edison Electric Light Co., October 7, 1886, New York. Reprinted in 5 THE ELECTRICIAN AND ELECTRICAL ENGINEER 468-73 (December 1886).

80 *USEL*, 52 F. 300 (2d Cir. 1892).

81 Franklin L. Pope, *Electricity,* 6 ENGINEERING MAGAZINE 92, 96 (1893); *See also* BRIGHT, THE ELECTRIC-LAMP INDUSTRY: at 89-90 ("[M]any new companies were formed after 1892 to produce '*non-infringing' lamps*. From 1892 till the expiration of the patent, there were probably ten or more competing producers making lamps at all times, despite the vigorous efforts of [GE] to close them down." (Our emphasis).

Edison's '898 Claim Elements	Non-infringing Improvement or Attempt to Design-Around Edison's Claim	Sponsor, assignee or user of the improvement	Inventor(s)	U.S. Patent No.	Filing Date (in 18YY)	Number of downstream patents citing or relying on this patent (See Appendix B)
Carbon Filaments (all claims)	Developed non-Carbon filaments by pioneering Chemical Vapor Deposition (CVD) to deposit the metals Niobium, Tantalum, Molybdenum, Titanium or Zirconium.	Aylsworth & Jackson Incandescent Filament Manufacturers	Jonas W, Aylsworth	553,296	27-Jul-94	16
				553,328	27-Jul-94	1
	Developed non-Carbon filaments made from metal deposits of Molybdenum, Tungsten, Rhodium, Iridium, Ruthenium, Osmium and Chromium	Westinghouse Electric Corp.	Alexander De Lodyguine	575,002	4-Jan-93	4
				575,668	10-Apr-94	4
	Developed filaments having cores of conductive oxides of earth metals coated with either Carbon, Silicon, Boron or a composition thereof	Thomson-Houston Electric Co.	Rudolf Langhans	420,881	5-Apr-88	4
… with a receiver made *entirely of glass*, (Claim 2)	Novel hermetically sealed connector for a two-part lamp	Western Electric Co.	Charles E. Scribner	584,750	24-Apr-93	4
	Improved stopper and conductor seal for a two-part lamp	Westinghouse Electric Corp.	Frank S. Smith	520,088	28-Jun-93	
… and *conductors passing through the glass* … (Claim 2)	Developed lamp stem with improved cement seal and support for leading-in wires not passing through the glass	Beacon Vacuum Pump and Electrical Co.	William E. Nickerson	500,670	1-Apr-93	1
				501,531	6-Apr-93	1
				503,671	17-Jul-93	1
				507,558	5-Aug-93	1
			Edward E. Cary	500,053	7-Apr-93	1
	No wires passing through the glass. Powdered silver fused in glass serve as electrical conductors to power the filament	Buckeye Electric Co.	Edward Pollard	485,478	2-Mar-92	5
	No wires passing through the glass. Secondary closed-coil filament powered from a primary coil by magnetic induction		Edward A. Colby	498,929	15-Feb-93	1
				499,097	15-Feb-93	2
				558,634	21-May-94	1
	Invented the celebrated Tesla Coil generator to light incandescent lamps by electromagnetic induction, without connection of two "conductors passing through the glass."	Westinghouse Electric Corp.	Nikola Tesla	454,622	25-Apr-91	13
						519
				514,170	2-Jan-92	1
… from which receiver *the air is exhausted*, for the *purposes set forth* (Claim 2)	Avoiding vacuum in the glass receiver by employing a low-pressure filling of Bromine. Heavy gases such as Bromine reduce bulb blackening.	Waring Electric Co.	John Waring	497,038	4-Jan-93	6
	Developed filament hermetic encasing structures using solid insulators such as mica. No glass receivers "from which the air is exhausted" were used.		Francis M. F. Cazin	523,460	7-Dec-92	7
				523,461	24-Jul-93	7
				566,285	24-Jul-93	7
Total number of patents in survey				**22**		**607**

Table 2. Sample of inventions discussed in the text that both designed-around Edison's patent and fostered significant downstream inventions. See Appendix B2 for an expanded version of this table, listing patents and adjudications that cite these 22 patents

Patents describing non-infringing designs filed after Appeal Court affirmance and before Edison's patent expiration	
Non-infringing design feature	**Number of patents**
Two-Part/Stopper lamp	27
Conductors not "passing through the glass"	19
Non-Carbon filament	4
Non-vacuum containment	4

Table 3. Number of incandescent lamp patent filings of applicants other than Edison/GE describing non-infringing lamp designs grouped by their design.[82]

In another investigating step, we sought more detail on the manner in which Edison's claim was designed-around. Table 3 shows the breakdown for 36 non-infringing designs described in patents filed between October 4, 1892 and the expiration date of Edison's patent in November 19, 1894, (epoch 5). This table shows that Two-Part/Stopper lamp designs dominated the "non-infringing" patenting activities during the injunctive enforcement of Edison's patent. Of 27 such designs, 16 were also using conductors not "passing through the glass." Although fundamental stopper lamp patents had existed prior to this period and even before Edison's invention, the technology had not been brought to a commercially adequate state and this necessitated additional *inventions* and investments as described in Appendix B1, Subsections B1.1 and B1.2. As discussed above, the empirical characteristic time of the "design-around" surge was 1.4 years from the October 1892 appeals court decision – the time it took for inventions-around and filing patent applications thereon. For the most part, these could not have been prior inventions that Edison's rivals sat on or hoarded because doing so after reduction to practice would have risked patent forfeiture under Revised Statute 4886. (See 4, 2nd Par.). Figure 4 shows that development intensity aggregated over *all* patenting activities in the incandescent lamp classes actually accelerated during the enforcement of the `898 patent.

The commercial success of non-infringing lamps shaped the remedies ordered by courts in patent infringement suits brought by GE, as injunctions were specifically tailored to give defendants an option to transition to the use of non-infringing lamps.[83] Such a transition was costly and was normally financed by the infringing lamp suppliers.[84]

We illustrate in Appendix B1 the diversity of the inventions-around and technologies that were covered in lamp patents that we categorize as "non-infringing" filed after Edison's assertion of his patent in 1886. We infer from the categories shown in Figure 5 that many inventions avoided, or presumably attempted to avoid, Edison's `898 patent claims, "designing-around" the claim limitations. We also use forward citations to identify later technologies that, but for the efforts to introduce non-infringing lamp designs around Edison's ´898 patent claims, would not have been developed, or would likely have been delayed.

5.3 The economic and legal characterization of designs around Edison's `898 patent

We see in Appendix B1 that regardless of immediate *commercial* significance in the incandescent lamp market, several designs-around later became *technologically* significant: this is evidently so for the Tesla Coil, De Lodyguine's pioneering work on earth metal filaments, Aylsworth's metal CVD methods and Scribner's hermetically-sealed connectors. In De Lodyguine's 1893 patent we have found the first use of tungsten as a filament material; a line of research with great future commercial value.

All these outcomes contradict the notion that efforts to design around patents are a waste or "duplicative R&D" (see Section 1). This perhaps should not surprise, as actual duplication of R&D ("imitating" a patentee) can only result in the *same* (infringing) solution whereas R&D efforts for designing-around a patent claim, *purposely* take different non-duplicative paths with the *object* to produce *different* and prospectively *patentable* results. We see here how the patent law fosters diversity in R&D paths: Edison/GE did not engage in electromagnetics R&D that could have produced Tesla's or Colby's methods of powering filaments; Edison had long ruled-out R&D on metals for filaments – the very subject of De Lodyguine's and Aylsworth's R&D; and GE did not need to engage in R&D on hermetically-sealed connectors as did Scribner at Western Electric. Edison's original research path, being foreclosed to other inventors, necessarily

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[82] A single patent may contain multiple design features, thus the number of patents in all design categories exceeds the total number of patents in this group (36).

[83] *See Edison Electric Light Co v. Mount Morris Electric Light Co*, 57 F. 642, 647 (C.C.N.Y. September 19, 1893).

[84] Francis W. Willcox, *Incandescent Lamps,* 149 JOURNAL OF THE FRANKLIN INSTITUTE 282, 295 (1900).

incentivized them to pursue alternative and *distinct* technologies that might lead to the same lucrative commercial market that Edison had unleashed.

Evidently, the established lamp manufacturers had not engaged in "duplicative R&D" and for the most part turned to technologies developed by designing around the Edison patent and to inventions independently developed by others. For example, for its design-around, Westinghouse acquired the Sawyer and Man stopper-lamp and flashing patents and had licensed or acquired interest in Tesla's and De Lodyguine's patents; Packard, Imperial Electric, Buckeye Electric, and the Boston Incandescent Lamp Company acquired licenses from independent inventor Pollard to manufacture his attempted design around the Edison patent using fused powdered silver conductors,[85] and Waring made his gas-filled lamp available through several manufacturers. These arrangements are consistent with the trend initiated in the late 19th century where the growing competitiveness of product markets induced firms to purchase or otherwise obtain the rights to technologies developed by others,[86] including from individual independent inventors.[87]

5.4 The crowding of the field of electric incandescent lamp manufacturers

Only a few of the design-arounds reviewed in Appendix B1 were commercially successful, but where they enabled rival lamp producers to remain in the lamp market or the entry to this market of new rivals, one might expect them to limit in some degree the market control attainable by the enforcement of the `898 patent. In this and the following sections we assess forms of commercial evidence that bear on this question.

The diversity of incandescent lamp manufacturers and suppliers was manifested brightly at the World's Fair Columbian Exposition of 1893 in Chicago. Within their respective exhibits at the fair, they operated a total of nearly 29,000 lamps: GE (10,000 lamps), Westinghouse (5,000), Western Electric Co. (5,500), Brush Electric Co. (1,500), Siemens Halske Co. (1,500), Fort Wayne Electric Co. (250), the Eddy Electric Manufacturing Co., the C. & C. Motor Co., the Mather Electric Co., and the Jenney Electric Motor Co. operated an aggregate of 2,000 lamps, and the smaller exhibitors operated an aggregate of 3,000 lamps.[88]

Figure 6 shows that the number of active firms in the field of incandescent lamps *almost doubled during the period of the Edison patent's enforcement* and therefore more vigorous competition in the field took place *after* his patent was upheld by the courts. We suggest that this rise occurred when it did because the economic incentive to market new and non-infringing lamps ensued only after GE began enforcing Edison's patent.

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[85] EDWARD J. COVINGTON, THE ELECTRIC INCANDESCENT LAMP, 1880-1925 154 (E.J. Covington 1998); Edward J. Covington, *The Lamp of Edward Pollard,* 2006, http://web.archive.org/web/20161010061110/http://home.frognet.net/~ejcov/pollard.html.

[86] NAOMI R. LAMOREAUX & KENNETH L. SOKOLOFF, *Inventors, Firms, and the Market for Technology in the Late Nineteenth and Early Twentieth Centuries, in Learning by Doing in Markets, Firms, and Countries* 19 (N. R. Lamoreaux et al. ed., University of Chicago Press 1999); Naomi R. Lamoreaux, Kenneth L. Sokoloff & Dhanoos Sutthiphisal, *Patent Alchemy: The Market for Technology in US History,* 87 BUSINESS HISTORY REVIEW 3 (2013)

[87] B. Z. KHAN, THE DEMOCRATIZATION OF INVENTION: PATENTS AND COPYRIGHTS IN AMERICAN ECONOMIC DEVELOPMENT, 1790-1920 (Cambridge University Press 2005)

[88] J. P. BARRETT, ELECTRICITY AT THE COLUMBIAN EXPOSITION 12 (R. R. Donnelley 1894).

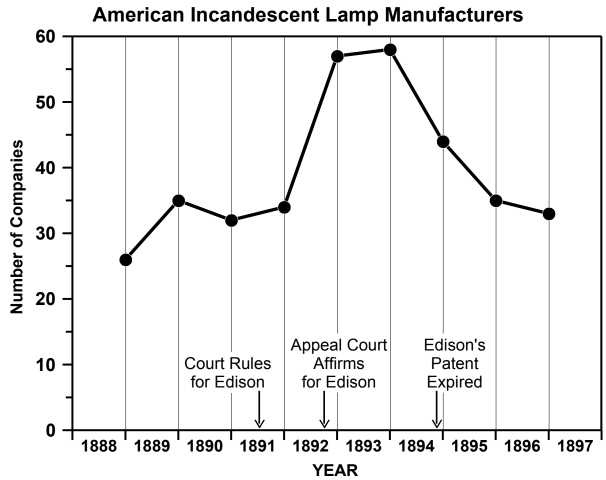

Figure 6. The number of active incandescent lamp manufacturers in America by year. *Source*: count of distinct manufacturers in trade magazine advertisements compiled by Bright.[89]

5.5 The decline in prices of incandescent lamps

Appendix C contains the details on historic lamp prices and Figure 7 shows sales prices for incandescent lamps from 1881 to 1905. The Edison/GE prices are shown in solid staircase line. As the figure shows, GE cut its lamp prices three times in 1893. The first GE price cut that year (to 52½ cents) was made in February, only a couple of months after Westinghouse introduced its non-infringing stopper lamp in full force as a response to Edison's injunction ruling of October 1892. Also shown are the price reductions of non-infringing lamps from Westinghouse and the Beacon Company, undercutting GE's prices by as much as 50%. The remarkable aspect of this 14-year long price trajectory is that *the most precipitous price declines took place during the enforcement of the Edison patent*. The sequence of events during this period suggests that GE was responding to, rather than leading, these price moves.

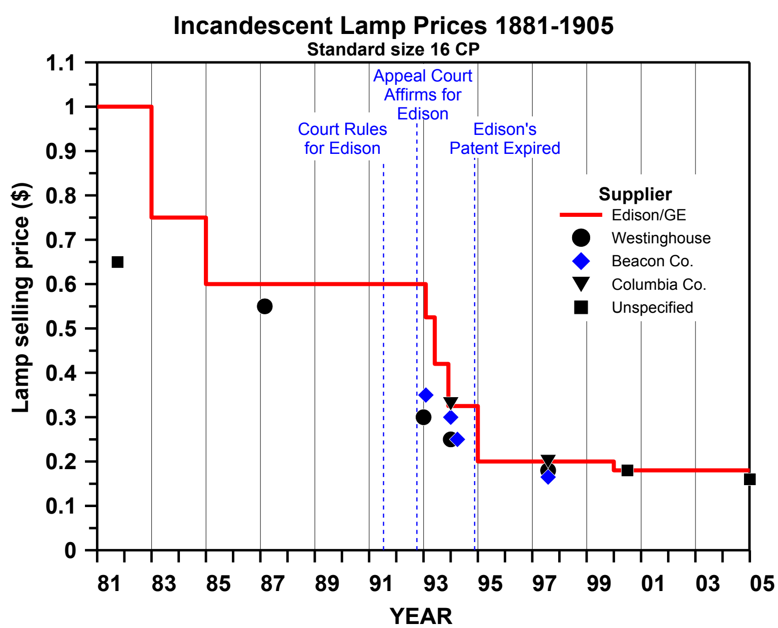

Figure 7. Selling prices of standard 16-candle incandescent lamps between 1881 and 1905. *Sources*: see Appendix C.

[89] BRIGHT, THE ELECTRIC-LAMP INDUSTRY, at 92, Table XI.

5.6 A stable Edison/General Electric's incandescent lamp market share

Figure 8 shows that no dramatic change had occurred in GE's rivals' aggregate market share after GE began enforcing the Edison patent. Note that while there was a decline in lamp sales in 1892, the decline was across the board, including in Edison/GE's sales, consistent with the substantial decline in general building infrastructure expenditures in 1892 that preceded the financial panic of 1893.[90] Note also that the slight increase of Edison/GE's share to about 52% in 1893 was inevitably due to the inclusion of Thompson-Houston sales in the GE figures for the first time. Moreover, it is remarkable that GE's market share in 1894 (through most of which Edison's patent was in force) declined appreciably, perhaps due to the aggressive underpricing of its competitors' non-infringing lamps (see Figure 7).

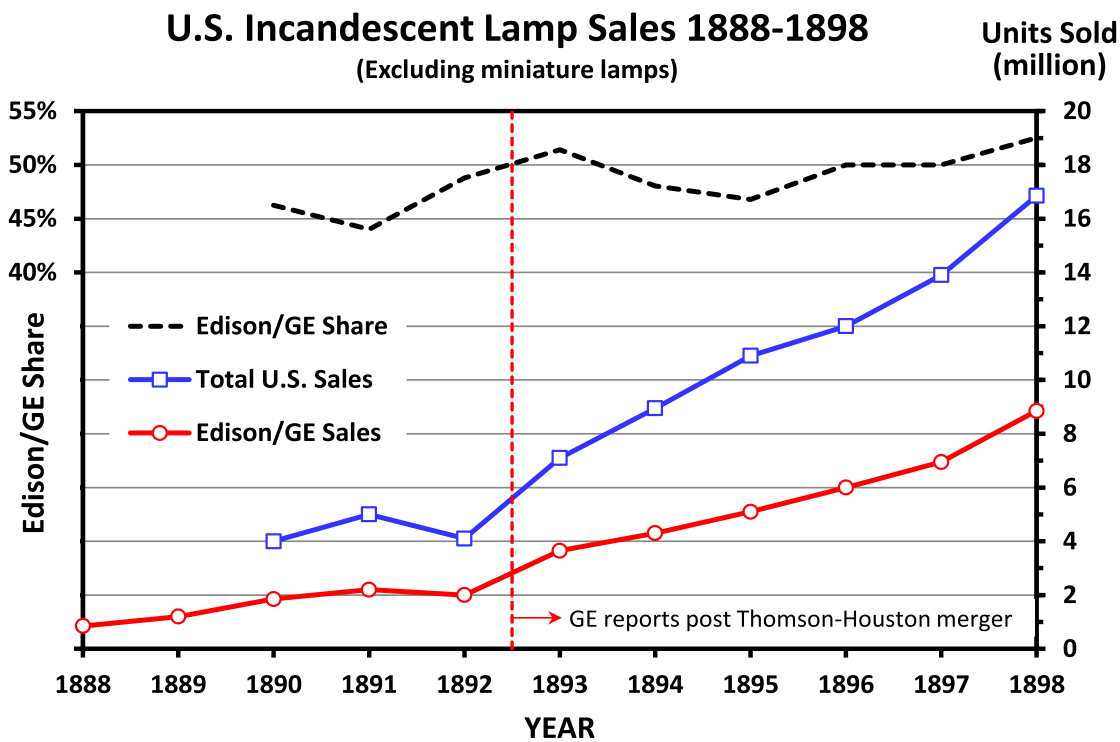

Figure 8. Total U.S. Incandescent lamp sales and the market share of the Edison and General Electric Company. The market share percentage graph for Edison/GE corresponds to the left coordinate axis. *Sources*: see Appendix C.

The market share data in Figure 8 is also consistent with Bright's statement that in 1896 "the lamp division of General Electric itself handled about half the domestic lamp business"[91] and with Passer's 50% estimate of GE's share at that time.[92] Data for GE's competitors' lamp unit market share were not available but we obtained a point estimate based on a relevant proxy for Westinghouse's share and estimate it to have been about 25% (see Appendix C).

6 Conclusion – Patent enforcement spurs downstream development

We found that key events in the legal trajectory of Edison's patent altered the inventive behavior of others as understanding and certainty of the value of Edison's patent was established. We show that it took nearly two years after Edison's patent issued for his industry contemporaries to appreciate and adopt in their patents the teaching of his invention and to abandon their unsuccessful prior approaches. When Edison filed infringement suit in 1886 there was a surge of patenting activity on inventions related to the Edison lamp technology. We interpreted this surge as actors in

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[90] For a description of this event, see DAVID O. WHITTEN, *The Depression of 1893, in* *EH.Net Encyclopedia* http://eh.net/encyclopedia/article/whitten.panic.1893 (Economic History Association 2010) (Building construction declined irregularly since April 1892)

[91] BRIGHT, THE ELECTRIC-LAMP INDUSTRY, at 104.

[92] PASSER, THE ELECTRICAL MANUFACTURERS, 1875-1900, at 162.

the field being spurred to capture key improvements on a broad range of technologies in a market that now appeared destined to be shaped by patent rights.

Our most important conclusion is that the surge of patenting after the 1891 court decision and its 1892 affirmance consisted of designs around Edison's `898 patent claims stimulated by the enforcement of this patent. Most of the technical specifications in these patents describe designs-around of the four constituent features of Edison's patent claims. Some of these design-arounds, such as Westinghouse's stopper lamps, provided commercially-viable and legal means to remain in the incandescent lamp field unaffected by GE's enforcement of the `898 patent. Other commercially-exploited designs tested with precision the enforceable boundary of the claims of the `898 patent, some with varying degrees of success (Waring's bromine-filled lamps and Beacon Company's cement seal stopper lamps). Still other design-arounds were not exploited commercially for the contemporary incandescent lamp market, such as the Tesla Coil.

Forward citation analysis of the inventive technological value of the design-arounds found that regardless of immediate *commercial* significance, several design-arounds were later *technologically* significant: these included the Tesla Coil, Lodyguine's path-breaking methods for coating platinum filaments with earth metals; Aylsworth's metal CVD methods; Colby's magnetically-coupled powering of illuminants; and Scribner's hermetically-sealed connectors. This outcome contradicts the widespread notion that efforts to design around patents "duplicate" the R&D that generated the patent to be designed-around. The design-arounds cited here illustrate that not all, and perhaps not the most important positive contributions to social welfare from R&D are captured by economic analysis confined to the commercialized technologies and markets which are often the direct object of purposeful R&D.

Given that the ability to design around the Edison patent both enabled GE rivals to remain in the lamp market (Westinghouse) and spurred new entrants to that market (Beacon Company), we examined the degree of GE's dominance in the incandescent lamp market before, during and after the enforcement period of the Edison patent. We found that during this period GE's market share did not increase; the number of firms in the incandescent lamp field rose; and GE made its steepest price reductions to its lamps - these lamp price reductions we suggest were a result of design-arounds that enabled low price lamp competition to the Edison lamp. The conclusion is clear; the restrictive licensing policy and the enforcement of the Edison patent cannot be associated by this evidence with an increase in GE's control over the incandescent lamp market, but the patent's enforcement *was* successful in stimulating inventive efforts to design around the patent claims.

Studying the downstream influence of Edison's patent, we see the patent system at work as intended by the U.S. Constitution, Article. I, §8, cl. 8 —"to promote the progress of … useful arts." In observing designs around Edison's claims in the *patents* of others, we see it rewards inventors with exclusive rights for pioneering solutions that evade rights previously awarded to others. We also see the patent system at work through our citation analysis which showed that many design-arounds proved significant building blocks and prior art for later, novel technological fields far removed from the incandescent lamp field of Edison's day. Our analysis also demonstrates empirically an inherent claim-scope *regulation* feature of the patent system: the prior-art limiting the scope of a patent enables others to invent around it – an activity that stimulates new downstream technologies, which in turn form prior-art that limits the scope of subsequent downstream exclusive patent rights.

Previous work we cite has shown that design around patent claims is an important practice of the majority of innovation managers today. We have noted that the relevant aspects of patent law that govern patent enforcement, actions, defenses, responses, and incentives of industry actors today are substantially the same as those during Edison's day.

It follows that the inferences and lessons learned from the designs-around Edison's patent claims are fully applicable today. We argue that our novel method of establishing the extent and effect of designs around offers general utility. It may be included in the analysis of the degree of market power conferred or said to be conferred by a specific patent or group of patents. It offers experts a means to evaluate whether designs-around exist and should be included in the equitable factors that establish whether the issuance of an injunction or an exclusion order against patent infringers is in the public interest.

Online Appendix for
"Exclusive Rights Stimulate Design-Around: How Circumventing Edison's Lamp Patent Promoted Competition and New Technology Development"

Ron D. Katznelson and John Howells

Table of Contents

Appendix A – Electric lamp patent classifications

Edison's patent No. 223,898 is classified under the U.S. Classification system of the U.S. Patent Office in primary Class 313 for lamp apparatus. Within Class 313, the subclasses covering incandescent and discharge lamp apparatus are shown below. Class 445 covers processes, methods or instruments of making lamps or related components. The subclasses within Class 445 that relate to making lamps are also shown below.

Incandescent lamp apparatus or components thereof:

Class 313: Electric lamp and discharge devices

Subclasses included in search:

/271-279 With support and/or spacing structure for electrode – For filament

/315 Incandescent lamps

/316 Incandescent lamps – Plural filaments or glowers

/317 With envelope

/333 Electrode and shield structures – Filament or wire shield or electrode

/341-345 Electrode and shield structures – Filament or resistance heated electrodes[93]

/548 Incandescent lamp gettering

/557 Incandescent lamp type

/569 With gas or vapor – Having a particular total or partial pressure – Incandescent lamp

/578 -- With gas or vapor – Incandescent filament lamp

/233 Involving particular degree of vacuum

USPTO database search string for this class category:

```
(CCL/313/548 OR CCL/313/557 OR CCL/313/569 OR CCL/313/578 OR CCL/313/233 OR CCL/313/27? OR CCL/313/315 OR CCL/313/316 OR CCL/313/317 OR CCL/313/333 OR CCL/313/34?)
```

Process, method or instrument for making incandescent lamps or components thereof:

Class 445: Electric lamp or space discharge component or device manufacturing

Subclasses included in search:

/6 Process – With start up, flashing or aging

/20 Process – Generating gas or vapor within an envelope, or coating by vapor, gas, mist or smoke within the envelope – Filament heating

/27 Process – With assembly or disassembly - Incandescent lamp making

/32 Process – With assembly or disassembly - Including electrode or getter mounting - Incandescent filament mounting

/38-43 Process – With assembly or disassembly - Including evacuating, degasifying or gas, vapor, liquid or meltable or sublimable solid introduction

/48 Process – Electrode making – Incandescent filament making

/53-57 Process – Including evacuating, degasifying or getter or fluent material introduction

/58 Process – With coating, e.g., providing protective coating on sensitive area

/60-73 Apparatus

USPTO database search string for this class category:

```
(CCL/445/20 OR CCL/445/27 OR CCL/445/32 OR CCL/445/38 OR CCL/445/39 OR CCL/445/40 OR CCL/445/41 OR CCL/445/42 OR CCL/445/43 OR CCL/445/48 OR CCL/445/53 OR CCL/445/54 OR CCL/445/55 OR CCL/445/56 OR CCL/445/57 OR CCL/445/58 OR CCL/445/6$ OR CCL/445/7?)
```

[93] Replaced by "34?" for search efficiency because of equivalence in the 1830-1900 period.

After further analysis of the classification system,[94] we determined that these were the only two class categories pertinent to our study of specific lamps and related components, to which our search was limited. Although the subclasses we selected did not contain all the electric lamp patents filed during our period of interest, for the most part, patents in other classes involving lamps are not directed towards lamps or related components per se. Other such classes include: Class 314 (electric lamp and discharge devices: consumable electrodes) which mostly contains arc lamps; Class 315 (electric lamp and discharge devices: systems) which contains systems incorporating lamps circuits, cutout devices, generators and the like; Class 362 (illumination) which contains lamps within illumination devices; and Class 439, (electrical connectors) which contains combination of an electric lamp and electrical connector structure.

Under each of these two class categories listed above, we show the USPTO online patent database[95] search strings we used to limit the search results. Of course, patents classified in multiple subclasses were found but were counted only once.

Our interest was to cover all incandescent lamp related patents filed up to, and including 1898. We discovered that all patents classified in our class-categories were filed later than 1830 and therefore we began our absolute cumulative count shown in the vertical axis in Figure 4 from 1830. Because none of the patent databases to which we have had access contained sufficiently reliable data or retrieval fields for the filing dates of U.S. patents from the 19th century,[96] we began by selecting patents based on their issue dates, which are reliably available for this period on the USPTO online database. We then manually entered the filing date of each patent in our lamp patent database that met the criteria - classified within our class categories and filed on or before December 31, 1898.

In order to save exhaustive inspection of every patent issued after 1898 to see whether it was filed during our period of interest, we had to set an issue-date upper search limit beyond which we should not expect to find any patents meeting our filing date criteria. By investigating typical pendencies of samples of patents in our class categories issued in 1899-1901, we found that those were typically less than 6 months with only a few exceptions having pendencies up to 1 year. We verified that this short pendency was indeed the general case during the turn of the century by checking the patent pendency statistics published at that time by the U.S. Patent Commissioner and noted a remarkable small relative application backlog and a very short delay. The number of applications awaiting action on the part of the Office on July 1, 1899 was 2,989 out of 40,320 applications received that year; every first Office Action was issued within one month from date of filing, and every turnaround action on applicants' amendment was sent back within fifteen days of receipt by the Office [97]. On this basis we limited our search to patents issued no later than January 1st 1900.

Each of the composite search strings for the two class categories were used with the **`AND`** Boolean operator to find sets of patents that belong to both class categories and also on both sides of the **`ANDNOT`** Boolean operator to find sets of patents that belong to one set and not the other. The sets were further limited by issue date with the "**`AND ISD/01/01/1830->01/01/1900`**" operator.

Of all the "hits" found, 21 patents involving gas lamps, electric arc lamps, illuminated displays, or lamp sockets/holders were excluded because they were apparently misclassified or clearly not involving any pertinent incandescent lamp subject matter. 392 other patents met our criteria and were included in the analysis. Of these, 235 were classified only under "Apparatus" categories, 90 were classified only under "Process, method or instrument for making" categories; and 67 were classified both under "Apparatus" and under "Process, method or instrument for making." These three groups are shown in Figure 4 by their cumulative number according to filing date.

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[94] See USPTO's patent classification web page at www.uspto.gov/web/patents/classification/selectnumwithtitle.htm

[95] USPTO online database available at http://patft.uspto.gov/netahtml/PTO/search-adv.htm. In composite search strings longer than the limit, we found the alternative online database at www.freepatentsonline.com which employs the same query syntax, to accommodate longer strings while having superior response time.

[96] Both the Lexis-Nexis and Google databases have OCR-based filing date information but much of it is corrupted or missing for U.S. patents from the 19th century.

[97] U.S. PATENT COMMISSIONER, REPORT OF THE COMMISSIONER OF PATENTS TO THE SECRETARY OF THE INTERIOR FOR THE FISCAL YEAR ENDED JUNE 30, 1899 3-5 (Government printing office 1899).

Appendix B1 – The diversity of designs around Edison's patent: evidence of stimulated downstream development and competition

B1.1 Stopper Lamps

"Stopper" lamps, or lamps made of two parts, were the most commercially-significant design-around Edison's patent because they enabled Edison-GE rivals to retain market share through the period of enforcement of Edison's patent. Stopper lamps avoided the all-glass enclosure specified in Edison's `898 patent by having either a combination two-piece stem and envelope, or no stem at all (see Figure 9).[98] As Table 3 shows, stopper lamp improvements dominated the design-around efforts during the most critical period of Edison's patent's enforcement. Apart from Westinghouse, companies such as Sawyer Man, Packard, and New Beacon, produced stopper lamp designs. The Sawyer-Man basic stopper lamp techniques were prior art to Edison's patent and such lamps were available on the market for several years. However, improvements in manufacturing and sealing techniques for the two-part lamp were necessary and they started taking center stage after the 1891 ruling on Edison's patent claims. Figure 9 illustrates a conceptual structure of a stopper lamp and its features that circumvent Claim 2 of the '898 Edison patent. Edison's single-piece glass lamp was the technological and economic state-of-the-art but it did have disadvantages: it was more expensive to seal and was necessarily discarded in its entirety at the end of its filament life.[99]

The major player in the non-infringing stopper lamp market was the Westinghouse Electric Corporation.[100] It introduced its new stopper lamp to the market on October 6, 1892, [101] *two days* after an appellate court had affirmed the *USEL* district court decision. This prompt response was only possible because the company was prepared: it had conducted a non-infringement analysis of the Edison patent's claims and had launched vigorous development efforts after the *USEL* ruling in 1891 in anticipation of the 1892 court of appeal decision. This included the development of "ingenious machines" to quickly grind precision seals for stopper lamps[102] and inventions for the stopper lamp's improvement - for example patents filed by George Westinghouse himself in August and November 1892. U.S. Pat. Nos. 543,280 and 550,359.[103]

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98 COVINGTON, THE ELECTRIC INCANDESCENT LAMP, 1880-1925, at 9-10.

99 A significant commercial filament replacement business evolved to service the growing installed base of Edison lamps, apparently displacing Edison lamp sales. There were even patents on filament replacement and lamp refurbishing techniques (see U.S. Pat Nos. 363,909; 439,178; 470,471; 473,208; and 485,682). The Edison Company alleged the infringement of the `898 patent and succeeded in enjoining several lamp repair shops on the grounds that their action was not a "repair" process but a reconstruction of the Edison lamp. *See Edison Elec. Light Co. v. Davis Elec. Works,* 58 F. 878, 878-79 (C.C.Mass. 1893), *aff'd* 60 F. 276 (1st Cir. 1894).

100 BRIGHT, THE ELECTRIC-LAMP INDUSTRY, at 90.

101 Westinghouse Co., *To Users of Incandescent Lamps,* 21 THE ELECTRICAL WORLD xvii (1893)

102 CHARLES A. TERRY, THE EARLY HISTORY OF THE WESTINGHOUSE ELECTRIC & MANUFACTURING COMPANY; AN EXTENSION COURSE 68-71 (Educational Dept., Westinghouse Electric & Manufacturing Co. 1929).

103 QUENTIN R. SKRABEC, GEORGE WESTINGHOUSE: GENTLE GENIUS 139 (Algora Pub. 2007).

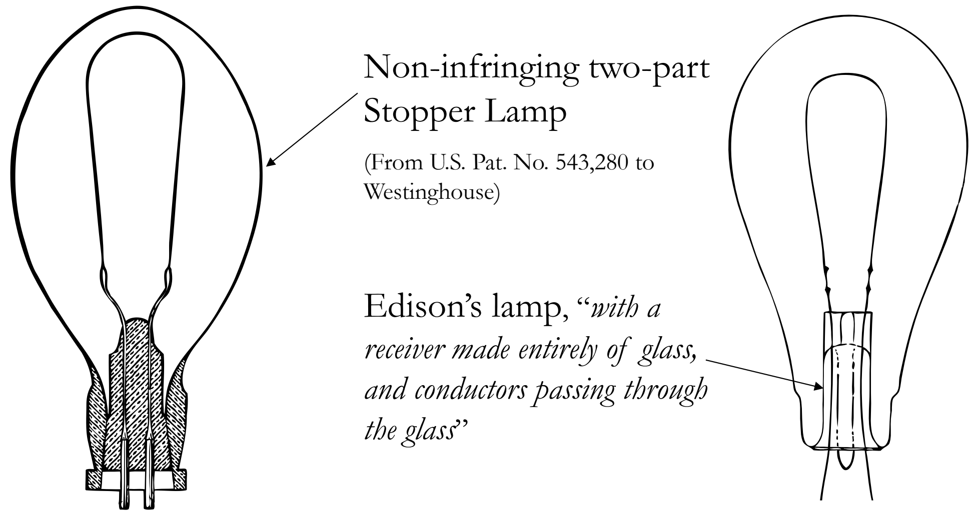

Figure 9**.** Comparison of Edison's all-glass globe lamp (right) and a stopper lamp (left). Edison's claim was limited to lamps with a globe made entirely of glass with conductors passing through the glass. The two-part stopper lamp did not infringe this claim because it had a stopper portion and because the conductors were not "passing through the glass."

Westinghouse advertised its technical competence and its commercial independence from the Edison invention when it won the contract to supply all electric lighting for the World's Fair Columbian Exposition that opened in Chicago in May 1893 and for which it manufactured 250,000 lamps.[104] Following the Fair, Westinghouse's 1894 annual report stressed that its stopper lamp enabled the Company to "protect all of its customers from the aggressive action of the owners of the Edison patent" and that "the price of incandescent lamps to the public at large has been greatly reduced in consequence of the success … in the production of non-infringing lamps."[105]

Evidence that the stopper lamp became a worthy economic rival to Edison's lamp comes from GE's own licensee who wrote bluntly to GE management: "it is of no use for you people to rest content with the conceited idea that the new [Westinghouse stopper] lamp is of no commercial value; as it is giving very good satisfaction here, and if, as we said above, they can go ahead with it, it is going to prove a formidable rival."[106] Westinghouse made substantial investments in glass and lamp factories, opening in February 1894 a new factory in Pittsburgh for mass production capacity of 10,000 glass vessels and stopper lamps per day.[107]

Westinghouse made significant improvements in the manufacturing processes and improved lifetime yields.[108] This made economically feasible Westinghouse's lamp refurbishment strategy which exploited the renewable two-part construction feature of the stopper lamp and two fundamental economic facts: in the early 1890s the electricity cost of powering an Edison lamp during its life was more than an order of magnitude greater than the cost of the lamp itself [109] and the lighting efficiency of incandescent lamps was inversely related to their time in use.[110] Refurbishment occurred at the end of a stopper lamp's life when the stopper could be removed and burned-out filaments could be replaced, thereby permitting reuse of the glass bulb, including the stem and connectors.

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[104] MARC J. SEIFER, WIZARD : THE LIFE AND TIMES OF NIKOLA TESLA: BIOGRAPHY OF A GENIUS 119 (Citadel Press 1998).

[105] Westinghouse Co., *Westinghouse Electric and Manufacturing Company 1894 Annual Report, Reprinted in:* 17 THE ELECTRICAL ENGINEER 438 (1894).

[106] PASSER, THE ELECTRICAL MANUFACTURERS, 1875-1900, at 161.

[107] Electrical World, *Pittsburgh Notes,* 23 THE ELECTRICAL WORLD 226 (1894)

[108] See U.S. Pat. No. 520,088 to Frank S. Smith of Westinghouse listed in Table 2.

[109] Carl Hering, *The most Economical Age of Incandescent Lamps,* X TRANSACTIONS OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS 63 (1893).

[110] Hering, *supra* note 109 at 63, Figures 2-3.

Further, the Westinghouse new stopper lamp achieved significant electric power savings over Edison's lamp as it employed a filament treatment technology ("flashing") owned by Westinghouse[111] that had improved the filament power efficiencies by more than 30% over untreated filaments (such as Edison's).[112] It also enabled precise manufacturing control of the filament's electrical resistance, substantially improving operating voltage uniformity.[113] These basic patents for "flashing," were arguably very important in the incandescent lamp industry. Generally, these treatment processes achieved their efficiency gains by facilitating higher filament temperatures during the first portion of the lamps' life. So the most economical lifetime of Westinghouse's improved stopper lamps were at around 250 operating hours,[114] shorter than Edison's lamps, and there were necessarily more frequent lamp replacements. However, given the economic dominance of electric power costs, the lamp's electric power savings compensated. In January 1893, the Westinghouse Company offered rebates for unbroken, burned-out lamps, making its net price for lamp renewal only 17 cents,[115] about one third of GE's lamp price at the time. Importantly, there was no consumer market for standardized light bulbs and the decision and responsibility for replacing light bulbs was that of the electric lighting company based on a totality of the economic value.[116]

The use of non-glass stoppers as insulators was a successful independent line of development in non-infringing stopper lamps taken up by the Beacon Vacuum Pump and Electrical Company of Massachusetts. Shortly after the Edison Electric Light Company had obtained an injunction in February 1893 against Beacon under the Edison patent,[117] Beacon introduced to the market its non-infringing lamp, known as the New Beacon Lamp. As with other lamps, the sealing problems addressed by the designers of these stopper lamps were not trivial, and the Company had apparently solved several stopper sealing problems and methods of hermetically securing the leading-in wires through impervious cement stopper that included heat dissipation solutions, the latter based upon 20 patents issued in the second half of 1893. A few representative Beacon lamp patents are listed in Table 2. Beacon had apparently licensed the Pennsylvania Electric Engineering Co. as a second-source supplier for the stopper lamp.[118]

Stopper lamp development had also been initiated in 1891 at Western Electric Co. by Charles E. Scribner, a prolific inventor with hundreds of patents to his name. He developed various hermetical seals (see U.S. Patent Nos. 563,319 and 563,321) and subsequently pioneered a new class of hermetically sealed connectors for implementing non-infringing two-part lamps. Scribner's stopper lamps incorporated his pioneering technology for making them with hermetically-sealed connectors as described in his U.S. Patent No. 584,750, which established the new field of hermetically sealed connectors (see Appendix B2).

The stopper lamp fulfilled a need for alternatives to Edison's lamp. While not superior overall, its economic viability and utility had proven satisfactory for this purpose, especially when coupled with filament refurbishing strategies. Improvements in stopper lamps for replacing filaments continued into 1897[119] but after the expiration of Edison's patent in November 1894 the use of stopper lamps diminished.[120]

B1.2 Lamps with no leading-in wires passing through the glass

Within this section are described four designs around Edison's Claim 2 on 'conductors passing through the glass' (Figure 1) that had little commercial importance in the lamp business of Edison's time, but very significant presence as prior art for later and distinct technological developments.

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[111] The fundamental Sawyer and Man Hydrocarbon deposition process was covered by U.S. Pat. Nos. 211,262 and 229,335. In 1892 Westinghouse engineer Frank S Smith further improved it. (U.S. Pat. No. 563,329).

[112] FRANKLIN L. POPE, EVOLUTION OF THE ELECTRIC INCANDESCENT LAMP 2nd ed. 77-82 (Boschen & Wefer 1894).

[113] JOHN W. HOWELL & HENRY SCHROEDER, HISTORY OF THE INCANDESCENT LAMP 79-80 (Maqua Co. 1927).

[114] Calvert Townley, *The Incandescent Lamp from a Commercial Standpoint,* PROCEEDINGS OF THE NATIONAL ELECTRIC LIGHT ASSOCIATION, 16TH CONVENTION 337, 350 (1893).

[115] Westinghouse Co., *supra* note 101; Electrical Review, *The New Westinghouse Lamp and Electric Lighting in America,* 32 THE ELECTRICAL REVIEW 113 (1893).

[116] Hering, *supra* note 109.

[117] *Edison Elec. Light Co. v. Beacon Vacuum Pump & Elec. Co*., 54 F. 678 (C.C.Mass. 1893).

[118] COVINGTON, THE ELECTRIC INCANDESCENT LAMP, 1880-1925, at 10.

[119] See U.S. Pat. No. 605,498 filed on Jul 17, 1897, describing a design for an annular lamp base structure that permits low cost filament replacement.

[120] TERRY, THE EARLY HISTORY OF THE WESTINGHOUSE ELECTRIC & MANUFACTURING COMPANY, at 71.

Non-glass stoppers, as in the cement stoppers of the New Beacon lamp introduced in 1893, avoided infringement of Edison's claim because the stoppers were not glass and the leading-in wires were not "passing through the glass." A more fundamental circumvention of Edison's claim powered the illuminant without having any conductors passing through the lamp vessel. One such invention by Edward A. Colby, used A.C. magnetic induction transformer with the primary winding on the outside of the bulb and the secondary connected to the filament on the inside. Three of Colby's patents are listed in Table 2. The first, U.S. Pat. No. 498,929, was cited as the pioneer prior art reference in a photoflash lamp patent filed more than 63 years later, describing a class of camera flash lamps that, in a similar manner, required no direct electrical connection for activation (see Appendix B2). Colby's principle is used today in more efficient, modern high frequency induction lamps in which transformer action is used to magnetically induce a current directly in the gaseous plasma ring .

It is not widely known that Nikola Tesla had invented the celebrated Tesla Coil in order to light incandescent lamps by *electromagnetic* induction. Tesla did so without direct connection of two conductors "passing through the glass" (Claim 2, Figure 1). Tesla's patent for the Tesla Coil – a high-frequency and high voltage generator, is in fact an electric lighting patent for which Tesla applied in 1891 and later issued U.S. Patent No. 454,622.

Tesla's patents resulting from his non-infringing lamp developments have been cited in modern electrodeless light bulb patents as pioneering prior art in the field (see Table 2 and Appendix B2). Tesla's celebrated demonstration in New York in 1891 of the first electrodeless lamp has been recognized as the seminal pioneering event in this segment of the lighting industry. [121] As Appendix B2 also shows, the Tesla Coil disclosure was relied upon by, and likely has limited the scope of, *at least 530 subsequent patents in wide technology areas*. It was cited as prior art in a patent infringement litigation case (note (c), Appendix B2), and even constituted prior art barring a patent in at least one patent application, which the U.S. Patent Office rejected in 1901 (note (b), Appendix B2). Tesla later used his Coil in his pioneering 1897 invention of the synchronized spark-plug ignition system for internal combustion engines (U.S. Pat. No. 609,250), the underlying technique used in modern automobile electrical ignition systems.

Inventor Edward Pollard filed on March 2, 1892, a patent application on a lamp without leading-in *wires* (U.S. Patent No 485,478). Instead of platinum wires, it utilized powdered silver films fused into the glass as conductors. Several manufacturers, including the Packard Company, Imperial Electric Manufacturing Company, the Buckeye Electric Company and the Boston Incandescent Lamp Company were making the lamp.[122] In January 1894, the Buckeye Electric Co. introduced its version of this lamp to the market with considerable national publicity.[123] GE's affiliate, the Edison Electric Light Company, sued the Boston Incandescent Lamp Company for infringement. Edison prevailed and obtained an injunction on June 11, 1894. In its opinion, the court pointed out that Edison's claim does not recite "wires" but rather the broad term "conductors"[124] (Claim 2 Figure 1). This particular attempt at non-infringement failed because the lamp was found to *literally* infringe Edison's second claim – the powdered silver channels were "conductors."

B1.3 Gas-filled, or non-vacuum lamps

Gas-filled design-arounds attempted to evade that element of Edison's Claim 2 that specified a lamp with a receiver "from which … the air is exhausted." Such designs also addressed the problem of progressive blackening due to carbon vapors of the inner surface of the evacuated bulb. In an attempt to avoid infringement and to simultaneously address the blackening of lamps, the Star Electric Lamp Company introduced the "New Sunbeam" lamp in 1893 filled with heavy gas, apparently hydrocarbon.[125] In 1894, the Waring Electrical Company introduced the 'Novak' lamp, which contained a low-pressure filling of bromine. The lamp was based on John Waring's patent, Pat. No. 497,038, applied for on January 4, 1893.

Edison/GE enjoined the manufacturing and sale of the Waring lamp on the grounds that the lamp infringed Edison's claim literally as it was made from a receiver from which, prior to filling with miniscule amounts of bromine, *first* "the air

[121] D. O. Wharmby, *Electrodeless Lamps for Lighting: A Review,* 140 IEE PROCEEDINGS-A 465 (1993) (Explaining that by creating a high frequency field in a room, Tesla demonstrated that "the mere suspension of the tubes in the room would afford the desired illumination.")

[122] COVINGTON, THE ELECTRIC INCANDESCENT LAMP, 1880-1925; Covington, *The Lamp of Edward Pollard*, *supra* note 85.

[123] Electrical Engineer, *The Buckeye Lamp without Leading-in Wires,* 17 THE ELECTRICAL ENGINEER 55 (1894)

[124] *Edison Elec. Light Co. v. Boston Incandescent Lamp Co*., 62 F. 397, 398 (C.C.Mass. 1894).

[125] BRIGHT, THE ELECTRIC-LAMP INDUSTRY, at 132; Edward J. Covington, *The 'New Sunbeam' Or 'Acorn' Lamp,* 2005, *available at* http://web.archive.org/web/20161010062020/http://home.frognet.net/~ejcov/kammer2.html.

is exhausted, for the purposes set forth." Although Waring urged that unlike Edison's lamp, his lamp did not use a vacuum, the court construed Edison's claim according to its plain language: the claim did not recite a lamp receiver exhausted to a vacuum but rather a lamp receiver "from which receiver the air is exhausted." [126]

Waring's pioneering work on gas-filled lamps did not produce commercially useful results with carbon filament lamps in his day. His approach, however, became important prior art two decades later when metal filaments were successfully introduced in an enclosed inert gas atmosphere [127]. As shown in Table 2 and Appendix B2, Waring's gas-filled lamp patent had been cited as the pioneer prior art in at least 6 patent cases relating to inert gasses and new filament materials. By using nitrogen-filled lamps in conjunction with a new construction of a tungsten filament, Irving Langmuir perfected Waring's approach, ushering-in higher efficiency tungsten lamp technology. Langmuir's key tungsten filament technology was patented on April 18, 1916 (U.S. Pat. No. 1,180,159) and the patent owner, GE, introduced it commercially as the new Mazda C lamps.[128] GE asserted Langmuir's patent in a 1919 case (note (d), Appendix B2), in which the Waring '038 patent was used as basic prior art for gas-filling benefits. In sustaining the patent, the court distinguished Langmuir's claims over Waring's '038 prior art, necessarily preventing overbroad construction of Langmuir's claims.

A radical variant, but technological-dead end design-around within this class of non-infringing designs was that by Francis M.F. Cazin. In a series of patent applications that Cazin filed immediately after the Edison injunctions took effect, he described lamps employing filaments embedded in hermetically sealed solid mica encasing structures, thereby avoiding Claim 2's "glass receivers from which the air is exhausted." He was apparently the only one to cite his patents (Table 2 and Appendix B2).

B1.4 Non-carbon filament lamps

Prior to Edison's invention there had been attempts to use platinum and other metal filaments to produce a practical commercial lamp but all had failed. In Edison's `898 patent a filament of carbon is an essential limitation in *all four* of the `898 patent claims (Figure 1). The `898 patent would be decisively and legally evaded if a commercially-viable metal filament lamp could be designed.

Hirst credits Lawrence Poland with the first attempt to use a non-carbon filament after Edison's success with carbon filaments.[129] Only 10 months after Edison asserted his patent against USEL in 1886, Poland filed in 1887 his patent application, issued as U.S. Pat. No. 432,710, describing lamp filaments made with iridium in a two-part stopper lamp.

In 1888, the German scientist Rudolf Langhans developed lamp filaments having cores of conductive oxides of earth metals coated with carbon, silicon, boron or a composition thereof and patented it under U.S. Pat. No. 420,881. The Thomson-Houston Electric Company brought Langhans to America in 1889 to develop this technology into a non-infringing substitute for carbon.[130] A contemporary scholar of incandescent metal filaments opined that Langhans' experiments brought him "within a hair's-breadth of producing a lamp the efficiency of which would have been as high or higher than that of the best type of metallic filament lamps at present [1912] obtainable."[131] Nevertheless, Langhans' pioneering work in conductive metal oxide filaments became fundamental prior art for later developments in semiconductor devices and thin film resistors, as shown in Table 2 and Appendix B2.

Of great significance for subsequent lamp development, Westinghouse hired Alexander De Lodyguine to work on coating platinum with other metals for use in non-infringing incandescent lamp filaments.[132] On January 4, 1893 and April 10, 1894 he filed patent applications issued as U.S. Pat. Nos. 575,002 and 575,668 respectively, covering processes for making filaments with rare-earth metals including tungsten. We found that this appears to be the first time that tungsten was suggested for lamp filaments. The eight downstream references to De Lodyguine's patents in Appendix B2 show that his pioneering work laid the foundation for the major advances in tungsten incandescent lamps as well as

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[126] *Edison Elec. Light Co. v. Waring Elec. Co.*, 59 F. 358, 364 (C.C.Conn. 1894).

[127] BRIGHT, THE ELECTRIC-LAMP INDUSTRY, at 132.

[128] BRIGHT, THE ELECTRIC-LAMP INDUSTRY at 318-322.

[129] H. Hirst, *Recent Progress in Tungsten Metallic Filament Lamps,* 41 JOURNAL OF THE INSTITUTION OF ELECTRICAL ENGINEERS 636 (1908).

[130] BRIGHT, THE ELECTRIC-LAMP INDUSTRY, at 121.

[131] GEORGE B. BARHAM, THE DEVELOPMENT OF THE INCANDESCENT ELECTRIC LAMP 30 (Scott, Greenwood & Son 1912).

[132] BRIGHT, THE ELECTRIC-LAMP INDUSTRY, at 120.

methods for making composite conductors and metallic joints. As further evidence of their fundamental nature, De Lodyguine's patents were the key prior art considered in GE's patent infringement suits that asserted its basic tungsten lamp patents (note (a), Appendix B2).

In 1894 the chemist Jonas W. Aylsworth independently pioneered a Chemical Vapor Deposition (CVD) process for coating filament cores with the metals niobium, tantalum, molybdenum, titanium or zirconium. On July 27, 1894 he filed patent applications for this process (issued as U.S. Pat. Nos. 553,296 and 553,328). Aylsworth describes the use of carbon or platinum as cores for the deposition process, permitting in the latter case the construction of non-carbon metallic filament. Although Aylsworth's attempts to manufacture niobium filaments[133] using his CVD process had apparently met with no commercial success, at least 17 downstream references cite his patents as pioneer prior art (Table 2 and Appendix B2). Aylsworth's non-infringing filament developments laid foundations in a new field of metal CVD, in which he is recognized as a pioneer.[134]

Mention must also be made of a design-around that ingeniously dispensed with the filament altogether. In late 1894 Daniel McFarlan Moore invented a phosphorescent electric lamp, the forerunner of modern fluorescent lamps.[135] His series of patents on phosphorescent lamps and related regulators were filed shortly after the Edison patent expired in November 1894 (U.S. Pat. Nos. 548,130; 548,131; 548,132; 548,133 and 548,574; 548,575; 548,576) and for this reason we omit them from Table 2 and Appendix B2. However, Moore had been working on his inventions during a period in which many researchers had been looking for alternatives and improvements to Edison's lamp. There is little doubt that these were in part efforts to "design around" Edison's claims that led to the conception of a whole new branch in the illumination industry – fluorescent lamps.

133 Electrical Engineer, *Niobium Filament Lamp,* 17 THE ELECTRICAL ENGINEER 169 (1896)

134 A. C. JONES & M. L. HITCHMAN, CHEMICAL VAPOUR DEPOSITION: PRECURSORS AND PROCESSES 2 (Royal Soc. Of Chemistry 2007).

135 BRIGHT, THE ELECTRIC-LAMP INDUSTRY, at 221; JOHN W. HAMMOND & ARTHUR POUND, MEN AND VOLTS; THE STORY OF GENERAL ELECTRIC 262 (J.B. Lippincott Company 1941).

Appendix B2 – Downstream patents citing designs around Edison's patent

The following three pages are tables of forward citations to the 21 patents describing design-arounds listed in Table 2. The tables contain a tally of all citations in downstream patents and legal cases that cite these 21 patents even if the patent at issue in the legal case had not included such citation. These provide a measure of the downstream collateral impact of Edison's `898 patent.

Edison's Claim Elements	Non-infringing Improvement or Attempt to Design-Around	Sponsor, Assignee or	Inventor(s)	U.S. Patent Number	Filing Date (in 18YY)	Downstream U.S. patents citing or relying on the improvement patent (including citations during adjudications)					
						U.S. Patent No. Or Publication Number	Filing Date	Title	Inventor(s)	Assignee	Adjudication note
Carbon Filaments (all claims)	Filaments by pioneering Chemical Vapor Deposition (CVD) to deposit the metals Niobium, Tantalum, Molybdenum, Titanium or Zirconium.	Aylsworth & Jackson Incandescent Filament Manufacturers	Jonas Walter Aylsworth	553,296	27-Jul-94	2,537,255	20-Mar-1946	Light-Sensitive Electric Device	Walter H. Brattain	Bell Telephone Laboratories	
						2,604,395	19-Nov-1945	Method of Producing Metallic Bodies	Bruce W. Gonser & Edward E. Slowter	Fansteel Metalurgical Corp.	
						2,756,166	27-Jan-1951	Vacuum Metallizing And Apparatus Therefor	Paul Alexander et al.	Continental Can Co.	
						2,822,301	3-Jun-1952	Vacuum Metallizing And Apparatus Therefor	Paul Alexander et al.	Continental Can Co.	
						2,873,108	23-Jul-1947	Apparatus for High Purity Metal Tecovery	Theodore T, Magel		
						2,873,184	25-Mar-1947	Thermal Decomposition of Uranium Compounds	Theodore T, Magel		
						2,873,185	23-Jul-1947	Deposition of Metal on Nonmetal Filament	Theodore T, Magel		
						2,978,358	28-Mar-1958	Method of Obtaining Uniform Coatings on Graphite	Ivor E. Campbell		
						2,990,293	13-Jan-1956	Method of Impregnating and Rust-Proofing Metal Articles	Henry A. Toulmin	Commonwealth Engineering Co.	
						3,020,148	5-Apr-1960	Production of Refractory metals	Wilmer A. Jenkins & Howard W. Jacobson	E.I du Pont	
						3,055,088	22-Sep-1958	Composite Metal Body for High Temperature Use	John J. Cox, Jr.	E.I du Pont	
						3,065,532	22-Apr-1958	Method Of Making Metallic Joints	Herbert B. Sachse	Keystone Carbon Co.	
						3,069,765	12-Dec-1956	Method Of Bonding And/Or Coating Metals	Clyde S. Simpelaar	Modine Mfg. Co.	
						3,089,949	28-Nov-1958	Arc Welding method and Article	Howard C. Ludwig	Westinghouse Electric Corp.	
						3,248,612	23-Jul-1962	Capacitor Electrode and method	Donald G. Rogers	Sprague Electric Co.	
						3,268,362	26-May-1961	Deposition of Crystalline Niobium Stannide	Joseph J. Hanak & John L. Cooper	Radio Corporation of America	
				553,328	27-Jul-94	2,640,798	27-Feb-1951	Method of Bonding	Nicholas Langer		
	Filaments of Molybdenum, Tungsten, Rhodium, Iridium, Ruthenium, Osmium, Chromium	Westinghouse Electric Corp.	Alexander De Lodyguine	575,002	4-Jan-93	872,936	19-Jan-1905	Tungsten Electric Incandescent Lamp	John Allen Heany		
						1,082,933	19-Jun-1912	Tungsten And Method Of Making The Same For Use As Filaments Of Incandescent Electric Lamps And For Other Purposes	William D. Coolidge	General Electric	
						4,525,379	6-Jan-1984	Method Of Manufacturing An Electrode For A High-Pressure Gas Discharge Lamp And Electrode For Such A Lamp	Horst Hubner	U.S. Philips Corp.	
				575,668	10-Apr-94	1,018,502	6-Jul-1905	Incandescent Bodies For Electric Lamps	Alexander Just & Franz Hanaman	General Electric	(a)
						1,010,866	23-Sep-1908	Process Of Making Composite Conductors	William D. Coolidge	General Electric	
						3,069,765	12-Dec-1956	Method Of Bonding And/Or Coating Metals	Clyde S. Simpelaar	Modine Mfg. Co.	
						3,065,532	22-Apr-1958	Method Of Making Metallic Joints	Herbert B. Sachse	Keystone Carbon Co.	
	Filament cores of conductive oxides of earth metals coated with either Carbon, Silicon, Boron or a composition	Thomson-Houston Electric Co.	Rudolf Langhans	420,881	5-Apr-88	2,547,406	8-May-1947	Method and Means for Controlling the Resistance of Oxidic Semiconductors	Francis J. Morin	Bell Telephone Labs., Inc.	
						2,594,921	23-May-1949	Fire or Temperature Rise Detecting Appliance	Arnold Hansard Douglas	Wilkinson Sword Co.	
						3,005,764	24-May-1948	Neutronic Reactor Structure	Farrington Daniels	The United States	
						3,242,006	3-Oct-1961	Tantalum Nitride Film Resistor	Dieter Gerstenberg	Bell Telephone Labs., Inc.	

Notes: (a) De Lodyguine patents were cited as prior art in: *General Electric Co. v. Laco-Philips Co.* 233 F. 96, 103 (C.A.2 1916); *General Electric Co. v. P.R. Mallory & Co.* 298 F. 579, 583 (C.A.2 1924)

Edison's Claim 2 Elements	Non-infringing Improvement or Attempt to Design-Around Edison's Claim	Sponsor, Assignee or user	Inventor(s)	U.S. Patent Number	Filing Date (in 18YY)	Downstream U.S. patents citing or relying on the improvement patent (including citations during adjudications)					
						U.S. Patent No. Or Publication Number	Filing Date	Title	Inventor(s)	Assignee	Adjudication note
a receiver made *entirely of glass*	Novel hermetically sealed connector for a two-part lamp	Western Electric Co.	Charles E. Scribner	584,750	24-Apr-93	2,688,737	13-Jan-1950	Hermetically sealed connector	Nick Oskerka Jr.	American Phenolic Corp.	
						3,055,465	3-Apr-1957	Metal-to-ceramic joint and method of forming	Hans Pulfrich	Telefunken GMBH	
						4,383,175	30-Sep-1980	Encapsulated scintillation detector	Ival L. Toepke	Bicron Corp.	
						5,548,116	1-Mar-1994	Long life oil well logging assembly	Kiril A. Pandelisev	Optoscint, Inc.	
. . . and ***conductors passing through the glass*** . . .	Developed lamp stem with improved cement seal and support for leading-in wires not passing through the glass	Beacon Vacuum Pump and Electrical Co,	William E. Nickerson	500,670		4,353,623	11-Jun-1980		Hermann F. L. Maier	U.S. Philips Corp.	
				501,531	6-Apr-93	3,069,583	30-Oct-1959	Electric Lamp	Samuel Swasey et al.	Sylvania Electric Products, Inc.	
				503,671	17-Jul-93	4,353,623	11-Jun-1980	Leadthrough for Electric Conductors	Hermann F. L. Maier	U.S. Philips Corp.	
				507,558	5-Aug-93	3,997,809	16-May-1975	Decorative lamp having an integral base and envelope	Robert J. Kyp		
			Edward E. Cary	500,053	7-Apr-93	2,826,710	28-Jul-1953	Reflector type lamp	Willis L. Lipscomb		
	No wires passing through the glass. Powdered silver fused in glass is the conductor powering the	Buckeye Electric Co.	Edward Pollard	485,478	2-Mar-92	2,569,848	31-May-1950	Electron Tube Seal Structure	William W Eitel & Martin E. Wolfe	Eitel-McCullough, Inc.	
						3,047,409	3-Feb-1955	Methods for Combining Metals and Compositions Containing Metals With Glass and Materials Produced	Games Slayter et al.	Owens-Corning Fiberglass Corp.	
						2,842,696	6-Oct-1955	Color Cathode Ray Image Reproducing Tube and Method	Erwin P. Fischer-Colbrie	General Electric	
						2,964,881	25-Oct-1956	Method of Making a Conductive Vitreous Seal	Johannes Cornelis Janssen	North American Philips Co.	
						2,950,414	Apr 1, 1959	Storage Tube	Richard D. Ketchpel	Hughes Aircraft Co.	
	No wires passing through the glass. Closed-coil filament powered by magnetic induction		Edward A. Colby	498,929	15-Feb-93	2,913,892	6-Aug-1956	Photoflash Lamp	William H. Fritz et al.	Union Carbide Corp.	
				499,097	15-Feb-93	5,309,541	16-Apr-1993	Flexible light conduit	Graham W. Flint	Laser Power Corp.	
						2,859,368	20-Oct-1951	Heat Lamp	Orrick H. Biggs & Stuart D. Davis	Sylvania Electric Products, Inc.	
				558,634	21-May-94	2,785,265	5-Dec-1952	Inductor	Winfield W. Salisbury	Zenith Radio Corp.	
	Invented the celebrated "Tesla Coil" generator to light incandescent vacuum lamps by electromagnetic induction, without direct connection of two ***conductors*** passing through the glass.	Westinghouse Electric Corp.	Nikola Tesla	454,622	25-Apr-91	568,176	22-Apr-1896	Apparatus for Producing Electric Currents of High Frequency and Potential	Nikola Tesla		
						568,177	17-Jun-1896	Apparatus for Producing Ozone	Nikola Tesla		
						514,170	2-Jan-1892	Incandescent Electric Light	Nikola Tesla		
						514,167	2-Jan-1892	Electrical Conductor	Nikola Tesla		
						514,168	2-Aug-1893	Means for Generating Electric Currents	Nikola Tesla		
						2,534,532	14-Jul-1945	High-Voltage Rectifier	Otto H. Schade	Radio Corporation of America	
						4,563,617	10-Jan-1983	Flat Panel Television/Display	Allen S. Davidson		
						5,506,596	26-Sep-1994	Reduced tension modular neon sign system	David Pacholok	Everbrite, Inc	
						6,104,107	11-Jan-1995	Method and apparatus for single line electrical transmission	Stanislav & Konstantin Avramenko	Uniline Ltd.	
						6,476,565	11-Apr-2001	Remote powered electrodeless light bulb	Michael Charles Kaminski		
						20050201715	14-Feb-2005	System, method, and computer program product for magneto-optic device display	Sutherland C. Ellwood Jr.	Panorama FLAT Ltd.	
						App. 653,809	2-Oct-1897	Electrical Machine	Albert Verley		(b)
						763,772	10-Nov-1900	Improvements in Apparatus for Wireless Telegraphy	Guglielmo Marconi	Marconi Wireless Telegraph Co.	(c)
						NexisLexis® found 519 U.S. patents with any of the terms "Tesla oscillating coil(s)", "Tesla coil(s)", "Tesla high-frequency coil(s)" or "coil! of the Tesla type"					
				514,170	2-Jan-92	4,563,617	10-Jan-1983	Flat Panel Television/Display	Allen S. Davidson		

Notes: (b) *Ex Parte Verley*, 99 OG 1621 (Sep 11, 1901) (U.S. Patent Commissioner affirming examiner rejection in view of Tesla's prior art), aff'd *In re Verley*, 19 App.D.C. 597 (C.A.D.C. 1902) (denying patent to Verley).

(c) *Marconi Wireless Telegraph Co. of America v. National Electric Signaling Co*. 213 F. 815 (D.C.N.Y. 1914) (Distinguishing over Tesla's prior art and finding the patent not invalid and infringed)

Edison's Claim 2 Elements	Non-infringing Improvement or Attempt to Design-Around Edison's Claim	Sponsor, Assignee or user	Inventor(s)	U.S. Patent Number	Filing Date (in 18YY)	Downstream U.S. patents citing or relying on the improvement patent (including citations during adjudications)					
						U.S. Patent No. Or Publication	Filing Date	Title	Inventor(s)	Assignee	Adjudication note
… from which receiver ***the air is exhausted***, for the ***purposes set forth***.	Avoiding vacuum in the glass receiver by employing a low-pressure filling of Bromine. Heavy gases such as Bromine reduce bulb blackening.	Waring Electric Co.	John Waring	497,038	4-Jan-93	1,180,159	19-Apr-1913	Incandescent Electric Lamp	Irving Langmuir	General Electric Corp.	(d)
						2,799,804	21-Oct-1952	Radar transmi receive Switch	Manfred A. Biondi	Westinghouse Electric Corp.	
						3,022,439	11-Mar-1960	Electric Lamps	Dexter P. Cooper, Jr.	Polaroid Corp.	
						3,470,410	16-Jan-1967	Bromine Regenerative Cycle Incandescent Lamps With Protective Overwind Coils On Coiled Filament Legs	Glenn F. Patsch	General Electric Corp.	
						3,475,649	18-Sep-1967	Tungsten Incandescent Lamps With Iodine Halides	Naoyoshi Nameda et al.	Tokyo Shibaura Electric Co.	
						3,538,373	3-Jan-1968	Electric Incandescent Lamp Containing A Reactive Carrier Gas Which Comprises Hydrogen And Bromine	P.C. Van der Linden & R.A.J. Maria Meijer	North American Philips Co.	
	Developed filament hermetic encasing structures using solid insulators such as mica. No glass receivers "from which the air is exhausted" were used		Francis M. F. Cazin	523,460	7-Dec-92	835,938	Feb 2, 1899	Electric Incandescent Lamp	Francis M. F. Cazin		
						844,778	Jul 27, 1899	Luminant In Electric Incandescent Lamps	Francis M. F. Cazin		
						877,172	21-Sep-1904	Method of Producing Filaments for Electric Incandescent Lamps and the Product of Such method	Francis M. F. Cazin		
						877,408	17-Mar-1904	Manufacture Of Electbic Incandescent Lamps	Francis M. F. Cazin		
						879,083	30-Nov-1903	Electric-Incandescent-Lamp Luminant and the Process of Manufacturing It	Francis M. F. Cazin		
						879,084	31-May-1904	Manufacture Of Filaments in Electbic Incandescent Lamps, Process and Product	Francis M. F. Cazin		
						879,085	2-Jun-1904	Filament In Electric Incandescent Lamps And Its Manufacture	Francis M. F. Cazin		
				523,461	24-Jul-93	835,938	2-Feb-1899	Electric Incandescent Lamp	Francis M. F. Cazin		
						844,778	27-Jul-1899	Luminant In Electric Incandescent Lamps	Francis M. F. Cazin		
						877,172	21-Sep-1904	Method of Producing Filaments for Electric Incandescent Lamps and the Product of Such method	Francis M. F. Cazin		
						877,408	17-Mar-1904	Manufacture Of Electbic Incandescent Lamps	Francis M. F. Cazin		
						879,083	30-Nov-1903	Electric-Incandescent-Lamp Luminant and the Process of Manufacturing It	Francis M. F. Cazin		
						879,084	31-May-1904	Manufacture Of Filaments in Electbic Incandescent Lamps, Process and Product	Francis M. F. Cazin		
						879,085	2-Jun-1904	Filament In Electric Incandescent Lamps And Its Manufacture	Francis M. F. Cazin		
				566,285	24-Jul-93	835,938	2-Feb-1899	Electric Incandescent Lamp	Francis M. F. Cazin		
						844,778	27-Jul-1899	Luminant In Electric Incandescent Lamps	Francis M. F. Cazin		
						877,172	21-Sep-1904	Method of Producing Filaments for Electric Incandescent Lamps and the Product of Such method	Francis M. F. Cazin		
						877,408	17-Mar-1904	Manufacture Of Electbic Incandescent Lamps	Francis M. F. Cazin		
						879,083	30-Nov-1903	Electric-Incandescent-Lamp Luminant and the Process of Manufacturing It	Francis M. F. Cazin		
						879,084	31-May-1904	Manufacture Of Filaments in Electbic Incandescent Lamps, Process and Product	Francis M. F. Cazin		
						879,085	2-Jun-1904	Filament In Electric Incandescent Lamps And Its Manufacture	Francis M. F. Cazin		

Notes: (d) *General Electric Co v. Nitro-Tungsten Lamp Co.* 261 F. 606 (D.C.N.Y. 1919) (Distinguishing over Waring's prior art and finding the patent valid and infringed).

Appendix C – Incandescent lamp prices and unit sales history

Edison/GE			Westinghouse			Beacon Co.			Columbia Co.		
Date	**Unit Price ($)**	**Source**	**Date**	**Unit Price ($)**	**Source**	**Date**	**Unit Price ($)**	**Source**	**Date**	**Unit Price ($)**	**Source**
Jan–1881	1	(a)	Mar–1887	0.55	(c)	Feb–1893	0.35	(f)	Jan–1894	0.33	(h)
Jan–1883	0.75	(a)	Jan–1893	0.3	(d)	Jan–1894	0.3	(g)	Aug–1897	0.2	(m)
Jan–1885	0.6	(a)	Jan–1894	0.25	(e)	Apr–1894	0.25	(k)			
Apr–1889	0.6	(a,b)	Aug–1897	0.18	(m)	Aug–1897	0.165	(m)			
Jan–1891	0.6	(a)									
Feb–1893	0.525	(a)							**Unspecified Supplier**		
Jun–1893	0.42	(a)									
Dec–1893	0.325	(a)									
Jan–1895	0.2	(a)							Oct–1881	0.65	(i)
Jan–1896	0.2	(a)							Jul–1900	0.18	(j)
Aug–1897	0.2	(m)							Jan–1905	0.16	(i)
Jan–1900	0.18	(a)									
Jan–1905	0.18	(a)									

Table 4. Selling prices of standard 16-candle incandescent lamps by supplier between 1881 and 1905. *Sources*: (a): 136; (b): Edison Papers at D8939ABB1; (c) Edison Papers at D8732AAL, 1893; (d): note 137, (e): note 138; (f): note 139; (g): note 140; (h): note 141; (i): note 142; (j): note 143; (k): note 144; (m): note 145, wherein the Sawyer-Man Co. is categorized as a subsidiary of Westinghouse Corp.

Table 4 shows sales prices to lighting companies for incandescent lamps from 1881 to 1905. The data is plotted in Figure 7 wherein the Edison/GE prices are shown in solid staircase line, depicting the complete set of annual price data disclosed by Henry Schroeder.[146] Schroeder was GE's sales engineering executive[147] and his data is independently corroborated for specific dates by other sources. These include a source in the Edison Papers from April 1889 and GE bids to the Government in August of 1897.[148] The important December 1893 GE price reduction to 32½ cents is also corroborated precisely by trade articles published weeks later.[149]

Incandescent lamp sales of Edison General Electric Company and the total U.S. sales are shown in Table 5. The market share percentage is calculated from the data. Unfortunately, data for GE's competitors' lamp unit market share were not available but we obtained a point estimate for the Westinghouse Company based on a relevant proxy for

[136] Henry Schroeder, *History of Incandescent Lamp Manufacture,* 14 General Electric Review 426, 428-29 (1911).

[137] Electrical Review, The New Westinghouse Lamp and Electric Lighting in America, 32 The Electrical Review 113 (1893).

[138] Electrical Engineer, *New Low Voltage Lamps of the Westinghouse Company,* 16 The Electrical Engineer 547 (1893)

[139] Beacon Co., *The New Beacon Incandescent Lamp – 35 Cent Price Advertisement by the Beacon Vacuum Pump & Electrical Co.* Proceedings of the National Electric Light Association, 16th Convention 434 (1893).

[140] Electrical Engineer, *Price of Beacon Lamps Reduced,* 17 The Electrical Engineer 40 (1894).

[141] Electrical Engineer, *New Price List of the Columbia Incandescent Lamp Company,* 17 The Electrical Engineer 40 (1894).

[142] J. T. Marshall, *The Development of the Manufacture of the Edison Incandescent Electric Lamp, 1881–1905,* 160 Journal of the Franklin Institute 21, 21 (1905).

[143] Willcox, *supra* note 84 at 293.

[144] Electrical Engineer, *New England Notes,* 17 The Electrical Engineer 313 (1894).

[145] Western Electrician, *Tabulated Prices of Electrical Supplies for the Government,* 21 Western Electrician 107 (1897).

[146] Schroeder, History of Incandescent Lamp Manufacture, 14 General Electric Review 426, 428-29(1911).

[147] Edward J. Covington, *Henry Schroeder,* 2003, *available at* http://web.archive.org/web/20131122000758/http://home.frognet.net:80/~ejcov/schroeder.html.

[148] Western Electrician, *supra* note 145.

[149] Electrical Engineer, *Reduction in the Price of Edison Lamps,* 16 The Electrical Engineer 497 (1893); Electrical Engineer, *Incandescent Lamp Economics,* 16 The Electrical Engineer 511 (1893).

Westinghouse's share – it's share of electric power stations' lamp serving capacity in 1890: 500,000 out of a total of 3,000,000.[150] This indicates that Westinghouse's installed base of lamps in service prior to Edison's patent enforcement was about 16%. We use the fact that electric lighting was generally sold as total systems made by one manufacturing company.[151] The distinct proprietary (often patented) sockets installed in these plants were incompatible among rival lamp suppliers, which ensured an exclusive continuous supply of one type of lamp to each plant contracting with that lamp's vendor. We also note that a replacement of sockets in customer premises was costly, troublesome and not generally used for changing lamp type.[152] While the use of lamp adapters for incompatible sockets was more practical, it required vendors' cooperation because sockets and mating lamp structures were patented by their respective manufacturers. Such cooperation only took place between Thomson Houston and Edison upon their merger into GE when some Thomson-Houston sockets received an Edison-to-Thomson Houston socket adapter.[153] The adapter developed by GE is described in U.S. Pat. No. 480,988 filed in May, 1892. Because majority of lamp vendors' sales were directed at replacements and expansion of their plants, the installed base should be a reasonable determinant for the lamp sales market share in the1890's.

U.S. Incandescent lamp sales (million units)
(excluding miniature lamps)

Year	Edison/GE	Total Market	Edison/GE Share
1888	0.85		
1889	1.20		
1890	1.85	4.00	46%
1891	2.20	5.00	44%
1892	2.00	4.10	49%
1893	3.65	7.10	51%
1894	4.30	8.95	48%
1895	5.10	10.90	47%
1896	6.00	12.00	50%
1897	6.95	13.90	50%
1898	8.85	16.85	53%
1899	10.00	21.75	46%
1900	12.00	24.60	49%

Table 5. Total U.S. Incandescent lamp sales and the market share of the Edison-General Electric Company. *Sources*: Edison/GE unit sales: note 154; Total U.S. unit sales: note 155.

It is with this view of the significance of lamp socket information that we note that a survey of the installed base of lamp sockets conducted six years after the expiration of Edison's patent reported that 15% of the installed lamp sockets were Westinghouse sockets.[156] This suggests that the enforcement of Edison's patent had insignificant effect on Westinghouse's market share. Based on illuminating companies' practices described in Section B1.1, we estimate that during Edison's patent enforcement, Westinghouse's (and presumably other vendors' non-infringing) stopper lamps were on average replaced twice as often compared to the Edison lamp. Given Edison's 50% unit market share (see Table 5 for that period) and Westinghouse's 1/6 socket market share, a simple calculation yields an estimated 25% *unit* market share for Westinghouse lamp sales during that time. Accordingly, all other lamp suppliers' unit market share would have been 25%.

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[150] PASSER, THE ELECTRICAL MANUFACTURERS, 1875-1900, at 206.

[151] *Edison Electric Light Co. et al. v. Sawyer-Man Electric Co.*, 53 F. 592, 595 (2nd.Cir.1892).

[152] Willcox, *supra* note 84 at 295.

[153] Willcox, *supra* note 84 at 294..

[154] Henry Schroeder, *Lamp Sales of the Edison Lamp Works during 1916,* 20 GENERAL ELECTRIC REVIEW 335 (1917) (Fig. 2).

[155] John Liston, *Some Developments in the Electrical Industry during 1917,* 21 GENERAL ELECTRIC REVIEW 4 (1918) (Fig. 84).

[156] Willcox, *supra* note 84 at 295.

Appendix D – Statistical analysis of patenting intensities

In this section, we characterize quantitatively and compare the patenting intensities of manufacturers other than Edison/GE designs for the two design categories – those patents describing designs that are considered non-infringing of Edison's incandescent lamp patent and those describing designs other than non-infringing, which we treat as the "Control." We also make certain statistical inferences based on estimated parameters of a patent counting model that accounts for the temporal development of the patenting intensities. Within the set of incandescent lamp patents identified in Appendix A, we consider only those of patentees other than Edison/GE. We denote by $\boldsymbol{n}(t)$ the cumulative count of patents applied for by time t that describe designs categorized as "*non-infringing*," and similarly denote by $\boldsymbol{m}(t)$ the cumulative count of all those describing designs categorized as "*other than non-infringing"* (see Figure 5). As shown in that figure, the observed processes $\boldsymbol{n}(t)$ and $\boldsymbol{m}(t)$ are staircase functions with unit jumps at times on which application filings occurred.

We partition the 19-year observation period since Edison's patent issued in 1880 into six distinct epochs T_e, $e = 1, 2, \ldots, 6$ as identified in the top rows of Table 6 and as shown in broken line epoch boundaries of Figure 5. As customary in modeling integer counting processes, we treat patent counts in a given time period as discrete integer random variables modeled as having a Poisson probability distribution. [157] This is particularly appropriate for hypothesis testing when the counts are small in some periods. We denote the total patent counts accumulated within epoch e as random variable integers $\boldsymbol{n}_e$ and $\boldsymbol{m}_e$ for patents describing non-infringing incandescent lamp designs and for all other designs (the "control") respectively. We therefore allow for distinct patenting intensities Λ_e and Γ_e as governing the observable counts $\boldsymbol{n}_e$ and $\boldsymbol{m}_e$ respectively, each having the Poisson probability density:

$$(2)\qquad \begin{aligned} \Pr\{\boldsymbol{n}_e = n\} &= f_{\boldsymbol{n}}(n;e) = \frac{\Lambda_e^n}{n!}\exp(-\Lambda_e)\,; \\ \Pr\{\boldsymbol{m}_e = m\} &= f_{\boldsymbol{m}}(m;e) = \frac{\Gamma_e^m}{m!}\exp(-\Gamma_e)\,; \end{aligned} \qquad \text{where } e = 1, 2, \ldots, 6\,.$$

For example, the quantity $f_{\boldsymbol{n}}(n;e)$ represents the probability that an underlying patenting intensity of Λ_e will produce $\boldsymbol{n}$ observed patents filed during the epoch e.

We limit our analysis to a model in which a possible coupling through economic scaling may empirically exist between the "control" patenting category and that of the non-infringing design category. This functional assumption of our model is the most basic way to capture the essence of the "control" aspect of $\boldsymbol{m}$ — it captures the general patenting trend accounting for common economic conditions and/or incandescent lamp market demand growth trends that are causally unrelated to the non-infringing aspects of these lamp designs.

Although under this model, the underlying intensities Λ_e and Γ_e, may be numerically related, we shall assume that $\boldsymbol{n}_e$ and $\boldsymbol{m}_e$ are otherwise *conditionally statistically* independent, that is, that

[157] Hausman, Hall & Griliches, *Econometric Models for Count Data with an Application to the Patents-*R *& D Relationship*, 52 ECONOMETRICA 909 (1984).

their joint probability density function conditioned on their intensities is the product of their individual marginal probability densities, conditioned on their respective intensities. This assumption is no different than assuming that two random variables having the same mean values are statistically independent. Similarly, although there may be temporal relation between the underlying intensities of the random counts $\boldsymbol{n}_e$ and $\boldsymbol{n}_{e-1}$ or $\boldsymbol{m}_e$ and $\boldsymbol{m}_{e-1}$ respectively in consecutive epochs, we shall also assume joint conditional statistical independence therebetween such that their joint conditional probability density function is given by:

$$(3) \qquad f_{\boldsymbol{nm}}(n_{e-1}, m_{e-1}, n_e, m_e \mid \Lambda_{e-1}, \Gamma_{e-1}, \Lambda_e, \Gamma_e) = f_{\boldsymbol{n}}(n_{e-1} \mid \Lambda_{e-1}) f_{\boldsymbol{m}}(m_{e-1} \mid \Gamma_{e-1}) f_{\boldsymbol{n}}(n_e \mid \Lambda_e) f_{\boldsymbol{m}}(m_e \mid \Gamma_e)$$

In other words, even though their underlying intensities may be proportionately coupled temporally or economically, we assume that the actual events of filing the patent applications within distinct epochs result in realization counts $\boldsymbol{n}_e$, $\boldsymbol{n}_{e-1}$, $\boldsymbol{m}_e$, and $\boldsymbol{m}_{e-1}$ that are jointly statistically independent random variables.

Difference-in-Difference Analysis

In studying the differential effect of a specific event separating consecutive epochs $e-1$ and e on non-infringing designs activity versus the "control" activity, we compare the change across the epochs $\log(\Lambda_e) - \log(\Lambda_{e-1})$ for non-infringing activity to the change $\log(\Gamma_e) - \log(\Gamma_{e-1})$ for the "control" activity. The degree to which the *difference in these differences* ("DID") significantly deviates from zero is indicative of the *divergence* of the possible effect of the specific event on introduction of non-infringing designs compared to the "control." We infer that the specific event caused no differential effect (and by implication was not the cause for changes in designing around) when the DID is zero—that is when:

$$[\log(\Lambda_e) - \log(\Lambda_{e-1})] - [\log(\Gamma_e) - \log(\Gamma_{e-1})] = \log\left(\frac{\Lambda_e \Gamma_{e-1}}{\Lambda_{e-1} \Gamma_e}\right) = 0; \text{ i.e., } \Lambda_e = \Lambda_{e-1}\left(\frac{\Gamma_e}{\Gamma_{e-1}}\right)$$

Given the patenting count $\boldsymbol{n}_e$ of non-infringing incandescent lamp designs and the patenting count $\boldsymbol{m}_e$ for all other designs (the "control"), we entertain two distinct groups of hypotheses with respect to observed temporal breaks in patenting trends between consecutive epochs $e-1$ and e. Starting with the second epoch, we formulate the hypotheses as follows:

> $\boldsymbol{H}_0(e)$: the change in the underlying patenting intensity Λ tracked the intensity of the control, Γ, meaning that the underlying patenting intensity during epoch e followed the "control." This means: $\Lambda_e = \Gamma_e \Lambda_{e-1} / \Gamma_{e-1}$.
>
> $\boldsymbol{H}_1(e)$: the underlying patenting intensity Λ changed between the consecutive epochs $e-1$ and e to a value other than that explained by $\boldsymbol{H}_0(e)$.

Under conventional statistical hypothesis testing practice, for each epoch $e \geq 2$, we test hypotheses $\boldsymbol{H}_1(e)$ against $\boldsymbol{H}_0(e)$, by forming the likelihood ratios $R(e)$ from the respective conditional joint probability densities. We then compare the respective prior probabilities Pr[$\boldsymbol{H}$] for each hypothesis and the conditional probabilities that each hypothesis is correct given the observable data $\boldsymbol{n}_{e-1}$, $\boldsymbol{n}_e$, $\boldsymbol{m}_{e-1}$, and $\boldsymbol{m}_e$. The likelihood ratio tells us how much more probable $\boldsymbol{H}_1(e)$ is relative to $\boldsymbol{H}_0(e)$ given the observed data. Using Bayes theorem for conditional probabilities, we have:

$$
(4) \quad \begin{aligned} R(e) &= \frac{\Pr[H_1(e) \mid \boldsymbol{n}_{e-1}, \boldsymbol{m}_{e-1}, \boldsymbol{n}_e, \boldsymbol{m}_e]}{\Pr[H_0(e) \mid \boldsymbol{n}_{e-1}, \boldsymbol{m}_{e-1}, \boldsymbol{n}_e, \boldsymbol{m}_e]} = \frac{\Pr[\boldsymbol{n}_{e-1}, \boldsymbol{m}_{e-1}, \boldsymbol{n}_e, \boldsymbol{m}_e \mid H_1(e)] \Pr[H_1(e)]}{\Pr[\boldsymbol{n}_{e-1}, \boldsymbol{m}_{e-1}, \boldsymbol{n}_e, \boldsymbol{m}_e \mid H_0(e)] \Pr[H_0(e)]} = \\ &= \frac{f_{\boldsymbol{nm}}\left[\boldsymbol{n}_{e-1}, \boldsymbol{m}_{e-1}, \boldsymbol{n}_e, \boldsymbol{m}_e \mid H_1(e)\right]}{f_{\boldsymbol{nm}}\left[\boldsymbol{n}_{e-1}, \boldsymbol{m}_{e-1}, \boldsymbol{n}_e, \boldsymbol{m}_e \mid H_0(e)\right]} \times \frac{\Pr[H_1(e)]}{\Pr[H_0(e)]} \end{aligned} .
$$

In our case, we take the ratio of the prior probabilities $\Pr[\boldsymbol{H}_2(e)]/\Pr[\boldsymbol{H}_i(e)]$ as unity because we have no prior reason to favor one hypothesis over the other. Given the formulation of the two hypotheses groups above and the joint density function of Equation 3, we have:

$$
(5) \quad \begin{aligned} R(e) &= \frac{f_{\boldsymbol{nm}}\left[\boldsymbol{n}_{e-1}, \boldsymbol{m}_{e-1}, \boldsymbol{n}_e, \boldsymbol{m}_e \mid H_1(e)\right]}{f_{\boldsymbol{nm}}\left[\boldsymbol{n}_{e-1}, \boldsymbol{m}_{e-1}, \boldsymbol{n}_e, \boldsymbol{m}_e \mid H_0(e)\right]} = \\ &= \frac{f_{\boldsymbol{nm}}\left[\boldsymbol{n}_{e-1}, \boldsymbol{m}_{e-1}, \boldsymbol{n}_e, \boldsymbol{m}_e \mid \Lambda_{e-1}, \Gamma_{e-1}, \Lambda_e, \Gamma_e\right]}{f_{\boldsymbol{nm}}\left[\boldsymbol{n}_{e-1}, \boldsymbol{m}_{e-1}, \boldsymbol{n}_e, \boldsymbol{m}_e \mid \Lambda_{e-1}, \Gamma_{e-1}, \Lambda_e = \Gamma_e \Lambda_{e-1}/\Gamma_{e-1}, \Gamma_e\right]} \\ &= \frac{f_{\boldsymbol{n}}\left[\boldsymbol{n}_{e-1} \mid \Lambda_{e-1}\right] f_{\boldsymbol{m}}\left[\boldsymbol{m}_{e-1} \mid \Gamma_{e-1}\right] f_{\boldsymbol{n}}\left[\boldsymbol{n}_e \mid \Lambda_e\right] f_{\boldsymbol{m}}\left[\boldsymbol{m}_e \mid \Gamma_e\right]}{f_{\boldsymbol{n}}\left[\boldsymbol{n}_{e-1} \mid \Lambda_{e-1}\right] f_{\boldsymbol{m}}\left[\boldsymbol{m}_{e-1} \mid \Gamma_{e-1}\right] f_{\boldsymbol{n}}\left[\boldsymbol{n}_e \mid \Lambda_e = \Gamma_e \Lambda_{e-1}/\Gamma_{e-1}\right] f_{\boldsymbol{m}}\left[\boldsymbol{m}_e \mid \Gamma_e\right]} \\ &= \frac{f_{\boldsymbol{n}}\left[\boldsymbol{n}_e \mid \Lambda_e\right]}{f_{\boldsymbol{n}}\left[\boldsymbol{n}_e \mid \Lambda_e = \Gamma_e \Lambda_{e-1}/\Gamma_{e-1}\right]} = \frac{\Lambda_e^{\boldsymbol{n}_e} \exp(-\Lambda_e) / \boldsymbol{n}_e!}{(\Gamma_e \Lambda_{e-1}/\Gamma_{e-1})^{\boldsymbol{n}_e} \exp(-\Gamma_e \Lambda_{e-1}/\Gamma_{e-1}) / \boldsymbol{n}_e!} \\ &= \left(\frac{\Lambda_e \Gamma_{e-1}}{\Lambda_{e-1} \Gamma_e}\right)^{\boldsymbol{n}_e} \exp(\Gamma_e \Lambda_{e-1}/\Gamma_{e-1} - \Lambda_e) \end{aligned} .
$$

Under the pertinent hypothesis, the patenting intensity parameters Λ_e and Γ_e of $\boldsymbol{n}_e$ and $\boldsymbol{m}_e$ are unknown. Therefore, we follow the traditional method described in Lehmann's textbook[158] and evaluate the likelihood ratios $R(e)$ by using the maximum likelihood estimates of the unknown parameters. It is a common textbook exercise to show that the maximum likelihood estimate for the intensity parameter of a Poisson random variable given an observation of its count is simply the observed count, and this estimate is statistically unbiased:

$$
(6) \quad \hat{\Lambda}_e = \boldsymbol{n}_e \; ; \; \hat{\Gamma}_e = \boldsymbol{m}_e \, ; \; E\left\{\hat{\Lambda}_e\right\} = E\left\{\boldsymbol{n}_e\right\} = \Lambda_e \, ; \; E\left\{\hat{\Gamma}_e\right\} = E\left\{\boldsymbol{m}_e\right\} = \Gamma_e \, .
$$

Using the likelihood ratio in Equation 5 above, and the estimated parameters from Equations 6, we obtain the following estimate for $R(e)$:

$$
(7) \quad \hat{R}(e) = \left(\frac{\boldsymbol{n}_e \boldsymbol{m}_{e-1}}{\boldsymbol{n}_{e-1} \boldsymbol{m}_e}\right)^{\boldsymbol{n}_e} \exp(\boldsymbol{m}_e \boldsymbol{n}_{e-1}/\boldsymbol{m}_{e-1} - \boldsymbol{n}_e) \, .
$$

In each respective epoch, the likelihood ratio is the ratio of the probabilities of only two possible mutually exclusive events – the patenting intensity changed proportionately with the "control" intensity, or it did not. Hence, we have $\Pr[\boldsymbol{H}_0(e) | \boldsymbol{n}_{e-1}, \boldsymbol{m}_{e-1}, \boldsymbol{n}_e, \boldsymbol{m}_e] + \Pr[\boldsymbol{H}_1(e) | \boldsymbol{n}_{e-1}, \boldsymbol{m}_{e-1}, \boldsymbol{n}_e, \boldsymbol{m}_e] = 1$, and based on the definition of the

158 ERICH L. LEHMANN, TESTING STATISTICAL HYPOTHESES 16 (Wiley 1959).

likelihood ratio in Equation 4, the estimated significance level $p(e)$ of rejecting $\boldsymbol{H}_0(e)$ in favor of $\boldsymbol{H}_1(e)$ (the probability that the null hypothesis $\boldsymbol{H}_0(e)$ is true given the observables) is therefore given by:

$$p(e) = \Pr[H_0(e) \,|\, \boldsymbol{n}_{e-1}, \boldsymbol{m}_{e-1}, \boldsymbol{n}_e, \boldsymbol{m}_e] = \frac{1}{1+\hat{R}(e)}. \tag{8}$$

The results of the calculations of the likelihood ratios and significance levels for rejecting $\boldsymbol{H}_0(e)$ in each epoch are shown in Table 6. Note that unlike traditional significance-level estimates that rely on the 'tail' of probability distributions that apply only for large counts, this result is unbiased and applies for any count number, including for certain epochs in our case having only 7 or 9 counts. The only assumption relied upon here is that the underlying joint probability density of the observed patenting counts is that of jointly statistically independent Poisson-distributed random variables.

Disclosed designs in patents by all manufacturers other than Edison/GE	*epoch (e)*	1	2	3	4	5	6
	Boundary Events	From patent issue to public exhibition	From public exhibition to patent lawsuit	Patent lawsuit to Sawyer & Man's patent defeat	From Sawyer & Man's patent defeat to patent lawsuit's final adjudication	Enforcement period of upheld patent	Post patent expiration
	Start Date	January 27, 1880	August 10, 1881	June 16, 1886	October 5, 1889	October 4, 1892	November 19, 1894
	End Date	August 10, 1881	June 16, 1886	October 5, 1889	October 4, 1892	November 19, 1894	January 1, 1899
	T_e (years)	1.53	4.85	3.30	3.00	2.12	4.11
Non-Infringing Designs	$\boldsymbol{n}_e$	15	11	10	13	36	9
	Avrg./Year	9.8 (2)	2.3 (0.54)	3 (0.76)	4.3 (0.95)	17 (2.25)	2.2 (0.58)
Designs Other than Non-Infringing ("control")	$\boldsymbol{m}_e$	27	82	33	25	7	14
	Avrg./Year	17.6 (2.69)	16.9 (1.49)	10 (1.38)	8.3 (1.33)	3.3 (0.98)	3.4 (0.72)
Statistical Inferences							
Likelihood Ratios	R		1.65E+08	1.31E+01	4.93E+00	5.94E+21	1.71E+19
Reject $\boldsymbol{H}_0$ at significance level	$\boldsymbol{p}$		**6.04E-09**	**0.07**	**0.17**	**1.68E-22**	**5.85E-20**

Table 6. Results of the statistical analysis and hypotheses tests covering six consecutive epochs.

As Table 6 shows, we can reject the null hypothesis with extreme confidence for all but the third and fourth epochs, which have a *p*-value greater than 0.05.

The mean absolute deviation of a Poisson-distributed random variable $\boldsymbol{n}$ from its mean value Λ is given by:[159]

$$E\{|\boldsymbol{n}-\Lambda|\} = 2\Lambda \Pr\{\boldsymbol{n} = \lfloor \Lambda \rfloor\} = 2\frac{\Lambda^{\lfloor \Lambda \rfloor + 1}}{\lfloor \Lambda \rfloor !}\exp(-\Lambda) \tag{9}$$

where $\lfloor \Lambda \rfloor$ is the integer part of Λ. We use this expression for estimating the mean deviation of the observable counts in each epoch by substituting Λ with its respective estimates in Equations 6, from which we obtain (by dividing these by the respective epoch duration) the mean deviation of the average patenting rates shown in Figure 3 and in parentheses in Table 6.

[159] T. A. Ramasubban, *The Mean Difference and the Mean Deviation of Some Discontinuous Distributions*, 45 BIOMETRIKA 549 (1958).